REPORT

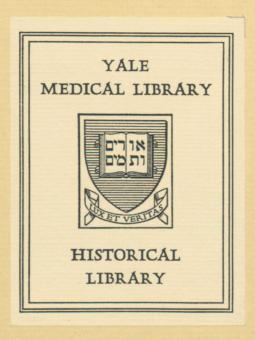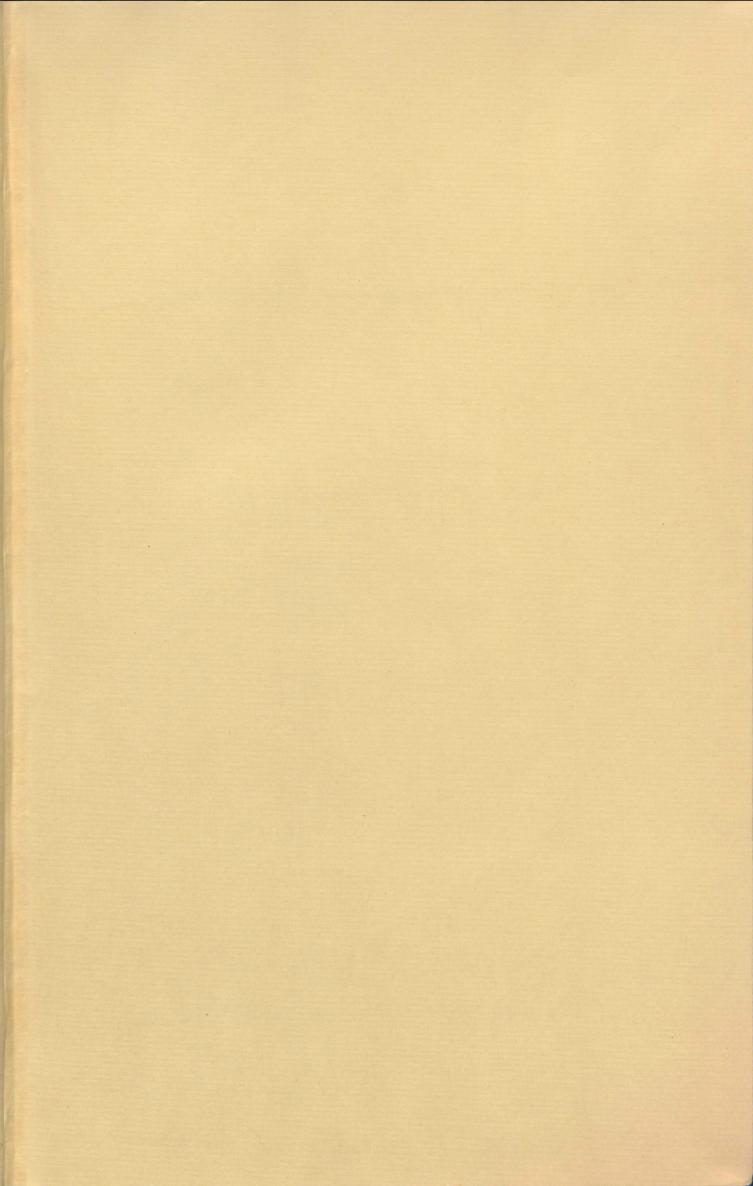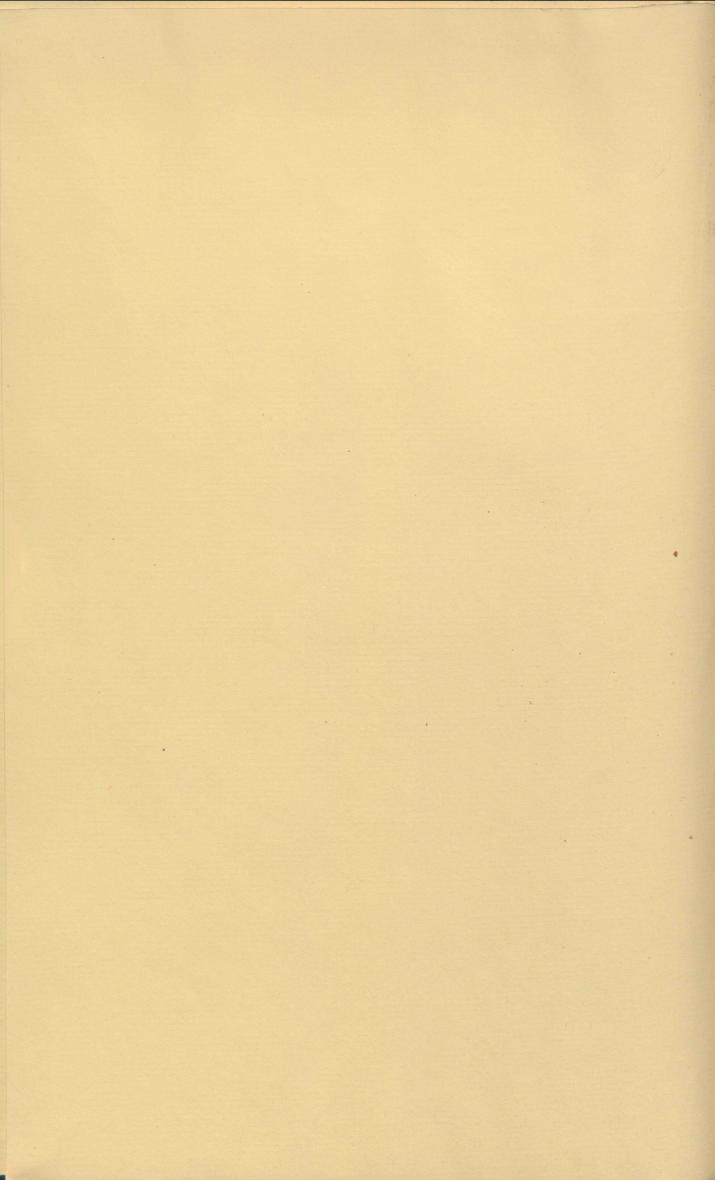## ON

THE ACTION OF WATER ON LEAD,

BY

WILLIAM CROOKES, F.R.S.,

WILLIAM ODLING, M.B., F.R.S., F.R.C.P.,

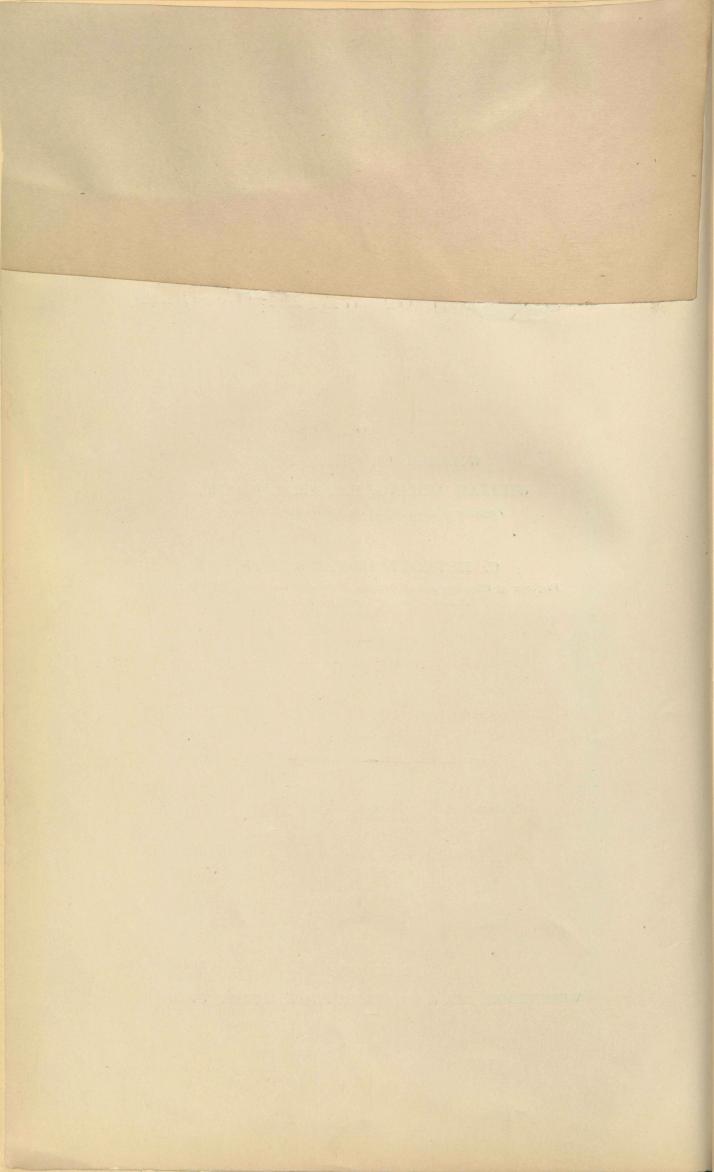*Professor of Chemistry at the University of Oxford ;*

AND

C. MEYMOTT TIDY, M.B., F.C.S.,

Professor of Chemistry and of Forensic Medicine at the London Hospital ;
Medical Officer of Health for Islington.

CONTENTS.

To the

WATER COMMITTEE OF THE CORPORATION OF HUDDERSFIELD.

Note.—All analyses of water are expressed in grains per imperial gallon of 70,000 grains, except the organic carbon and nitrogen, which are given in parts per 100,000. The free oxygen is expressed in cubic inches per gallon.

Gentlemen,

In accordance with instructions given us at a Meeting of your Committee on September 5th, 1882, we have been examining the circumstances under which the water supplied by Parliamentary authority to Huddersfield and its neighbourhood acts upon lead, with a view, more particularly, to our suggestion of some practicable means for preventing its action in the future. We would remind you of the precise position in which we found the subject at the time when we commenced our investigations. A case, indeed more than one case, of undoubted lead poisoning had occurred in Huddersfield; and, further, the plaintiff, in a case that was the subject of a trial at law, alleged that the water was in fault, owing to its special solvent action on the lead service pipes. It was indisputable—

1. That the person complaining suffered from lead poisoning.
2. That the water in the mains was itself of good quality and contained no lead.
3. That after passing through the service pipes supplying the house in which the plaintiff resided, the water contained lead.

In evidence before the Court, we stated, as in the then condition of knowledge we believed ourselves justified in stating, that the action of the Huddersfield water on lead was one common to soft waters generally; and that, until at any rate the occurrence of the case under consideration by the Court, there was not any reason to suppose that the danger of lead poisoning at Huddersfield was in any respect greater than at other towns supplied with water of similar softness. A difficulty, however, occurred in the case, the bearings of which were not at the moment easy of explanation. It had been shown that some of the Huddersfield water, although not the water supplied to the plaintiff, had a distinctly acid reaction. Mr. Jarmain stated, and in this we agreed with him, that the acidity depended on the presence of free sulphuric acid. This opinion was founded, *first,* on the existence of certain iron springs which found their way into the reservoir and byewash, and caused a considerable deposit of a basic sulphate and carbonate of iron at the point of entrance; and *secondly,* upon actual experimental observations made on the water. The question, however, was complicated by a suggestion that the acid present was not sulphuric, but hydrochloric acid, resulting from the action of free sulphuric acid, generated from the ochre springs, on the chlorides in the water; whilst yet a third suggestion was offered, namely, that the acid, in part at least,

A 2

was nitric acid, resulting from the oxidation of the nitrogen of the dissolved peat. This latter suggestion received considerable countenance from the remarkable disappearance of the free acid of the water at the end of the autumn. We may state that, in our opinion, no free hydrochloric acid is formed. Considering the extremely dilute condition of the primary free acid (taking it to be sulphuric), and the small quantity of common salt present in solution, it is contrary to our experience that any reaction of the acid on the salt would occur at ordinary temperatures. But it is possible that a portion of the free acid may be nitric acid, its formation being promoted by summer weather and the influence of a powerful light. In our opinion, therefore, the acidity may depend on the presence of nitric as well as of sulphuric acid. The question, however, what acid, or acids, are present is, we are convinced, a matter of but little importance. We have, in fact, abundant evidence to prove that the action of the water on lead has nothing whatever to do with its acidity.

It was, therefore, with the conviction that we should meet in other soft water towns with precisely the same result as at Huddersfield, that we commenced our investigations.

I.—ACTION OF HUDDERSFIELD WATER ON LEAD.

We have many times since 1882 inspected the reservoirs at Deerhill and Blackmoorfoot.

Deerhill Reservoir.—The water of Deerhill is derived from Millstone Grit moorland. We have on frequent occasions found this water acid, owing, in our opinion, mainly to the inflow of certain ochrey springs containing sulphate of iron, resulting from the oxidation of iron pyrites. But the water of the reservoir is not always acid. For example, on September 6th, 1882, we found it perfectly neutral. On this occasion it was tested at numerous points, including the outlet and the gauge basin, no trace of acidity being detected anywhere. We subjoin four analyses of the water. The reaction of samples I. and II. was neutral, while that of samples III. and IV. was acid.

DEERHILL WATER.

	I. Outlet of Reservoir.	II. Outlet of Reservoir (West Side).	III. Gauge Basin of Reservoir.	IV. Outlet of Reservoir.
Free Oxygen	2·01	1·91	—	—
Total Solids	2·55	2·57	3·80	3·0
Ammonia	0·00	0·00	0·004	0·0
Nitrogen = Nitric Acid ...	0·00	0·00	0·023 = 0·104	0·015 = 0·0675
Oxygen required to oxidise organic matter	0·040	0·036	0·018	0·026
Organic Carbon	0·051	—	0·067	—
Organic Nitrogen	0·025	—	0·030	—
Silica	0·130	—	0·160	—
Lime	0·224	0·280	0·412	—
Magnesia	0·144	0·152	0·288	—
Sulphuric Acid (combined)	Trace.	Trace.	Trace.	—
Chlorine = Common Salt	0·72 = 1·17	0·64 = 1·06	0·432 = 0·708	0·576 = 0·944
Hardness—				
Before boiling	2·9°	2·4°	2·0°	2·0°
After boiling	1·2°	1·6°	2·0°	2·0°

Blackmoorfoot Reservoir.—This reservoir is fed by two conduits. The water is often very slightly acid; but we have never found it so acid as the water of Deerhill not unfrequently is.

The results of five examinations are subjoined. Samples III. and IV. were very slightly acid, while the other three samples were neutral.

BLACKMOORFOOT WATER.

	I. Near Outlet Shaft (Northern Side).	II. Inlet at Gauge.	III. From Mains.	IV. Reservoir.	V. At Drawing Shaft.
Free Oxygen	2·12	1·940	1·910	1·73	1·810
Total Solids	4·10	3·950	2·900	4·86	3·280
Ammonia	0·00	0·001	0·001	0·00	0·001
Nitrogen = Nitric Acid	0·00	0·00	0·00	0·052 = 0·234	0·052 = 0·235
Oxygen required to oxidise, &c.	0·042	0·076	0·060	0·035	0·048
Organic Carbon	0·114	0·171	0·160	0·071	0·084
Organic Nitrogen ..	0·020	0·020	0·024	0·016	0·022
Silica..............	0·160	0·210	0·240	0·200	0·018
Lime..............	0·970	0·530	0·590	1·560	—
Magnesia	0·288	0·216	0·216	0·401	—
Sulphuric Acid (combined)	1·460	1·280	1·030	1·500	—
Chloride = Common Salt	0·64 = 1·06	0·64 = 1·06	0·64 = 1·06	0·792 = 1·298	0·576 = 0 944
Hardness—					
Before boiling	2·4°	2·2°	2·1°	2·3°	2·6°
After boiling . .	2·0°	2·0°	1·6°	2·0°	2·0°

The action of these waters upon lead has been examined in great detail. The following tabular statements, however, sufficiently indicate their solvent power :—

(*A*.) DEERHILL WATER, JUNE 28TH, 1880.

WATER NEUTRAL.

The water employed had a hardness of 2° before, and of 1·4° after boiling.

(*a*.) Sheet lead (3 in. × 1·5 in.) *completely* submerged in 2,800 grains of water :—

	Grains of lead dissolved per gallon after 24 hours.
Freshly-scraped bright lead	3·185
Old lead	0·317

(*b*.) Sheet lead *partially* submerged in 2,800 grains of water. (Portion submerged 2·8 in. × 1·5 in.) :—

	Grains of lead dissolved per gallon after 24 hours.
Bright new lead	5·725
Old lead	0·955

(*c*.) Pipe lead. New lead pipe (9 feet long, 1 inch diameter), completely filled with water. Grains of lead dissolved per gallon after 24 hours, 2·185.

(*B*.) BLACKMOORFOOT WATER, JUNE 28TH, 1880.

WATER NEUTRAL.

The water employed had a hardness before boiling of 2·1°, and after boiling of 2°.

(*a*.) Sheet lead (3 in. × 1·5 in.) *completely* submerged in 2,800 grains of water :—

	Grains of lead dissolved per gallon after 24 hours.
Freshly-scraped bright lead...	2·547
Old lead	0·300

(*b.*) Sheet lead *partially* submerged in 2,800 grains of water. (Portion submerged 2·8 in. × 1·5 in.) :—

	Grains of lead dissolved per gallon in 24 hours.
Bright new lead	3·185
Old lead	0·637

(*c.*) Pipe lead. New lead pipe (9 feet long, 1 inch diameter), completely filled with the water. Grains of lead dissolved after 24 hours, 0·928.

Our attention has been specially directed in these inquiries to the waters of Deerhill and Blackmoorfoot. Nevertheless, both Wessenden water (from springs) and Longwood water (also mainly spring water) have been examined, and the results of our experiments as to the action of these waters on lead are given in the following table :—

(*C.*) WESSENDEN AND LONGWOOD WATERS, June, 1880.

Both Waters Neutral.

(*a.*) Sheet lead (3 in. × 1·5 in.) *completely* submerged in 2,800 grains of water :—

	Grains of lead dissolved per gallon after 24 hours.	
	Wessenden.	Longwood.
Freshly-scraped bright lead...	3·810	1·272
Old lead	0·317	0·150

(*b.*) Sheet lead *partially* submerged in 2,800 grains of water. (Portion submerged 2·8 in. × 1·5 in.) :—

	Grains of lead dissolved per gallon after 24 hours.	
	Wessenden.	Longwood.
Freshly-scraped bright lead	4·725	3·800
Old lead	1·250	0·625

Some question arose concerning the action of the Brow Grains Dyke water. This water is derived, we are informed, from certain disused colliery workings, and finds its way into Blackmoorfoot Reservoir. We give herewith the composition of a sample taken on September 6th, 1882. It is sufficient to say that it has practically no solvent action on lead whatsoever, and is, in our opinion, of very good quality. Its reaction is distinctly alkaline :—

Total Solids	26·400	Lime	6·16
Ammonia	0·002	Magnesia	2·81
Nitrogen = Nitric Acid ...	0·000	Sulphuric Acid (SO_3) combined	6·65
Oxygen required to oxidise, &c.	0·026	Chlorine = Common Salt ... 0·64 = 1·06	
Organic Carbon	0·054	Hardness—	
Organic Nitrogen	0·040	Before boiling	16·5°
Silica	1·30	After boiling	9·0°

We examined numerous samples of Huddersfield water after its passage through service pipes. The amount of lead present in solution in these samples was found to be very variable. Sometimes it did not exceed 0·02 gr. per gallon, whilst in other samples as much as 0·6 gr. of lead per gallon was present. We found lead in the water drawn through service pipes that had been laid for many years.

II.—Chemical Principles involved in the Action of Waters on Lead.

Our examinations of water for lead were conducted in such manner that a quantity of lead equal to 0·01 grain per gallon could be estimated. (See page 55.) It would have been easy for us to employ methods —*e.g.*, by concentrating the water—whereby far smaller quantities of lead might have been determined, but we deemed this neither necessary nor advisable where so many experiments had to be made.

It is important to note the very different solvent powers of the same water for lead of different kinds and of different degrees of purity, and the consequent discrepancies in experiments conducted under but slightly varying conditions. We refer to this because if one experimenter reports a given water to dissolve 1 grain of lead per gallon, and a second experimenter reports it to dissolve 2 grains, neither need be incorrect. And the same remark, it must be admitted, applies more or less to the occasionally discordant results obtained by the same operator.

The chemical action of water on lead would appear to be as follows :—

I. The lead as an oxide, the oxygen being derived from air in solution, may be dissolved by the water. Pure aërated water dissolves from 6 to 8 grains of oxide of lead per gallon. By the action of carbonic acid upon this solution of lead oxide, carbonate of lead is precipitated. Carbonate of lead is soluble in water to the extent only of 0·02 grain per gallon. If a water containing six grains of lead oxide per gallon in solution be exposed to the air for 24 hours so as to admit of free contact, the dissolved lead is reduced to 0·02 of a grain per gallon, the remainder of the lead being thrown down as a carbonate.

When a water containing dissolved oxide of lead is filtered through new filter paper, the filtrate contains a very small percentage of the lead present in the unfiltered water. This was the argument originally employed to prove that oxide of lead was not dissolved by, but merely suspended in, the water. It was shown, however (Yorke, 1846), that the lead oxide entered into combination with the fibre of the filtering paper, and that after this fibre had become saturated, the dissolved lead passed through without detention.

Noad states that carbonate of lead is insoluble in water saturated with carbonic acid. Our own experiments show that a saturated solution of carbonic acid dissolves rather more carbonate of lead than the same water without the saturating carbonic acid.

II. The lead may be in suspension in a state of minute subdivision in the water. This may result from one of two causes, (*a*) from the carbonate of lead being actually formed in the water, or (*b*) from the carbonate of lead deposited on the pipe becoming detached therefrom by vibrations, such as would be caused by pumping, etc. Water which contains carbonate of lead in suspension is toxically as dangerous as that which contains oxide of lead in solution.

III. The lead compound formed may be adherent to the pipe; which suffers, of course, corrosion as well as incrustation.

Certain circumstances, irrespective of those appertaining directly to the character of the water, which influence the solubility of lead, have to be noted.

(*a.*) The activity of solution is greatly dependent on whether the water and lead be freely exposed, or be not freely exposed, to the air.

The action of ordinary distilled water (that is, of water containing some dissolved air) on sheet lead in *open* vessels is immediate, increasing continuously the longer the lead and water remain in contact. The lead is first oxidised, the lead oxide formed being dissolved by the water. Atmospheric carbonic acid throws down silky scales of lead carbonate mixed more or less with hydrated lead oxide. Precipitation having taken place, the water is then in a condition to dissolve more lead oxide.

The action of ordinary distilled water on sheet lead in *closed* vessels does not commence for two or three hours, a maximum being reached after at most 24 hours. If this clear water be exposed to the air, silky crystals separate, rendering the water turbid. When, instead of distilled water, Huddersfield water is employed, the results are similar, except that with the silky crystals of lead carbonate, flocculi of organic matter are also visible. Leaden pipes therefore, kept charged with water, as when the supply is constant, are less likely to be objectionable than where the supply is intermittent.

(*b.*) Great differences in the quantity dissolved result accordingly as the lead is wholly, or only partially, submerged in the water; the partially submerged metal suffering the more active dissolution.

(*c.*) Neither the quantity of lead dissolved, nor the rapidity of dissolution is influenced to the extent we should have expected, by placing one, two, three, or four pieces of sheet lead in the water, after a certain area of surface has been reached.

(*d.*) The position of the lead in the water is not unimportant, as regards the quantity dissolved. For example, if a slip of lead be laid flat at the bottom of a beaker, the lead dissolved is less than if the same surface be exposed vertically or in a slightly inclined position, because in the latter case the delicate scales formed fall off and subside, leaving a fresh surface of lead exposed to the action of the water.

This detail was noted by Dr. Penny, who says :—

The following experiment will serve to illustrate the influence of a slight variation even in the position of the lead. Five deep cylindrical vessels were filled with Loch Katrine water, and a slip of milled lead was immersed vertically in each, as explained in the following statement, which also shows the results obtained :—

				In 3 hours.
1st vessel, slip half immersed ...	...	...	...	$2\frac{3}{4}$ gr. per gall.
2nd „ „ just below the surface	...	...	...	$2\frac{1}{4}$ „
3rd „ „ $\frac{1}{3}$ below the surface ...	...	...	...	2 „
4th „ „ midway...	...	...	...	2 „
5th „ „ at the bottom ...	...	...	...	$\frac{3}{4}$ „

(*e.*) A slight increase of temperature occasions a greatly increased solvent action of the water. (See page 54). Although not materially different between 40° and 50° F., the quantity of lead dissolved is largely increased when

the temperature of the water is raised to 80° F. Dr. Penny carefully examined the influence of temperature in the case of Loch Katrine water. He says :—

The influence of temperature is well shown in an experiment, in which the vessel containing the water and lead was placed in an air bath, where it was exposed to a temperature of 100 degrees F. The water was cold at the commencement of the experiment. A comparative trial was also made with another portion of water at 60 degrees.

				At 100° F. Per Gallon.				At 60° F. Per Gallon.
1 hour	...	...	...	3 grains	...	...	...	$1\frac{3}{4}$ grains.
2 hours	...	...	...	8 ,,	...	...	...	$2\frac{1}{2}$,,
3 hours	...	...	...	11 ,,	...	...	...	4 ,,
4 hours	...	...	...	$12\frac{1}{2}$,,	...	...	...	$4\frac{1}{2}$,,

A similar experiment was made with two pieces of lead pipe of the same length and diameter. Both were filled with Loch Katrine water, and securely closed. One pipe was kept in the sun's rays for four hours, and the other at the ordinary temperature. On opening the pipes and testing the water, a notably larger proportion of lead was detected in that which had been in the pipe exposed to sunshine, as the following statement fully shows:—

			Temp. of Water.				Grains of Lead.
Water from pipe in sunshine ...	...	...	79°	...	...	...	$\frac{1}{3}$ in a gallon.
Water from pipe at 65°...	...	...	65°	...	...	...	$\frac{1}{8}$,,

It would therefore appear that the lead pipes in kitchens and other warm places would be more corroded and acted on than pipes in less heated situations.

We may note that although underground pipes preserve for the most part a fairly even temperature, many service pipes are, for a greater or shorter length, more or less exposed.

(*f*.) It has been stated (Anderson and Dugald Campbell) that, when the water and lead are kept in the dark, the solvent action is less than when under exposure to the light. Our experiments confirm those of Dr. Penny that this is a mistake, there being no appreciable difference whether the water be exposed to bright sunshine, or kept in total darkness, except so far as may be explained by the action of heat. Dr. Penny remarks :—

From a careful consideration of these experiments, I feel fully justified in affirming that Loch Katrine water acts *upon lead as powerfully in the dark as in the light, and that the increased action observable in the direct rays of the sun may be referred to the elevation of temperature*.

(*g*.) The solvent action of water depends to a very marked extent upon the form in which the lead occurs. We have many experiments to show that where lead is simply melted and then allowed to cool (*e. g.*, ordinary lead bullets), the action of distilled water is far less energetic than it is upon lead pipes ; whilst the operations and mechanical processes necessary to produce sheet lead, seem to render it more easily acted upon by water than even pipe lead. The severest test to which a water can be put, in testing its action on lead, is by subjecting it to contact with freshly scraped sheet lead.

(*h*.) We noted that some of the new lead pipes supplied to us were dull from the presence of a bluish grey coating (suboxide ?), whilst others were perfectly bright. We found the action of distilled water on the dull lead pipes was less, and sometimes less by one-half, than its action upon the bright pipes. Nevertheless, we have never met with new pipes upon which ordinary distilled water did not exhibit some solvent action.

(*i*.) The action of water on lead containing various admixtures of other metals has been carefully considered :—

B

Lead containing 7 per cent. of zinc appears to be dissolved with nearly twice the rapidity of pure lead.

The solvent action of water on lead containing 7 per cent. of tin was reduced by one-third. Lead with 1 and 2 per cent. of tin was also found to be less easily acted upon than pure lead. Anderson, Dugald Campbell, and Taylor consider a lead with 5 per cent. of tin to be proof against water. With this view we do not agree. Samples of commercial pipe lead have come before us, containing from 0·6 to 2·0 per cent. of tin.

Dr. Penny investigated this matter in connection with Loch Katrine water. He says :—

When alloys of lead with 5, 10, or 20 per cent. of tin are immersed in Loch Katrine water, no *visible* action takes place, even after many days' contact ; the water remains bright and transparent, and no pearly sedimentary matter is formed ; but *dissolved* lead can always be detected in the water. Four alloys were made, containing respectively 1, 5, 10 and 20 per cent. of tin. A piece of each, exposing nearly the same surface, was wholly immersed in Loch Katrine water in open vessels. The results are given in the following table :—

Alloys.		1 hour. Per gallon.		3 hours. Per gallon.		3 days. Per gallon.
1 per cent. of tin ...	...	$\frac{1}{15}$ gr.	...	$\frac{1}{2}$ gr.	...	$2\frac{1}{2}$ grs.
5 ,, ,, ...	...	$\frac{1}{20}$ gr.	...	$\frac{1}{8}$ gr.	...	$\frac{1}{3}$ gr.
10 ,, ,, ...	...	$\frac{1}{30}$ gr.	...	$\frac{1}{9}$ gr.	...	$\frac{1}{3}$ gr.
20 ,, ,, ...	...	$\frac{1}{40}$ gr.	...	$\frac{1}{10}$ gr.	...	$\frac{1}{3}$ gr.

No sedimentary matter was formed in any of these experiments, excepting in the case of the first alloy, which, after three days, gave the usual flaky deposit, the water becoming opalescent on agitation. The results in the above statement show that Loch Katrine water acts appreciably upon lead alloyed with tin, and that there is very little difference in the protecting power, whether the tin amounts to 5, 10 or 20 per cent. Again, several pounds of lead were alloyed respectively with 5 and 10 per cent. of tin. Part of each alloy was melted and cast, and the remainder was rolled into sheet at Messrs. Newton and Keates' works. The object of the experiment was to ascertain whether the mere operation of rolling influenced, in any marked degree, the protective power of the tin. The following results were obtained:—

Alloys.	CAST. 3 hours.		2 days.		ROLLED. 3 hours.		2 days.
5 per cent. tin ...	$\frac{1}{5}$ gr.	...	nearly $\frac{1}{3}$ gr.	...	$\frac{1}{8}$ gr.	...	nearly $\frac{1}{3}$ gr
10 ,, ,, ...	$\frac{1}{8}$ gr.	...	$\frac{1}{4}$ to $\frac{1}{3}$ gr.	...	$\frac{1}{3}$ gr.	...	$\frac{1}{3}$ gr.

Loch Katrine water, therefore, acts decidedly upon lead alloyed with tin, but much less powerfully than upon pure sheet lead.

It is worth recording that distilled water is said to have very little action on lead containing 2 per cent. of antimony, even where free access of atmospheric air is permitted.

Dr. Nevins (*Pharmaceutical Journal*, 1850-51, p. 595) states as his experience that the action of water on pipe and sheet lead is almost identical, pipe lead being, if anything, least affected. As regards tea lead, the action of water upon it was found by him to be at least 100 per cent. greater than on pipe and sheet lead. [No analyses of these leads are recorded.] He concludes, "Impurity in common pipe lead is more likely to be zinc than any other metal, and this would retard rather than hasten the action of the water on the lead by forming a galvanic arrangement, whilst the tin which is stated to be present in the tea lead would hasten the action upon the lead, as it is less easily acted upon by chemical agents than lead itself." It will be seen that our results are not in accord with those of Dr. Nevins.

(*k.*) Another question we have considered is, How far the solvent action of water on lead is lessened by its previous passage through iron pipes. Our results are somewhat conflicting. We are informed that Ennerdale Lake water acts on lead, even after flowing through six miles of iron pipes. We are disposed to think that, so far as contact with the iron lessens the amount of free oxygen in the water, by so much does it lessen the subsequent corroding action of the water on lead.

This was the subject matter of a report by Dr. Penny in the case of Loch Katrine water. He says :—

Many experiments have also been made to ascertain the effect of keeping Loch Katrine water in contact with iron before trying its action upon milled lead and piping. The water was kept in closed iron pipes for several days, and then quickly transferred to lead tubes. In a few hours the presence of lead was detected in the clear water. In six days as much as $\frac{1}{3}$ of a grain per gallon was dissolved ; and including the lead in the sedimentary matter, which is abundantly formed by the action of the water on the iron, I found nearly two grains. In the same way, sheet lead was invariably corroded by the water after the latter had been kept for many days in closed vessels with pieces of cast-iron. In one experiment, after 12 days' contact with iron, the water, in 24 hours, was found to contain $\frac{1}{8}$ of a grain per gallon. Its action on lead, after lengthened contact with iron, is therefore evidently diminished; but, when this is the case, the water becomes charged and foul with oxide of iron, and is rendered thereby quite unfit for use, though it still retains the power of becoming impregnated with a poisonous quantity of lead.

Graham and Hofmann, however, from a series of analyses, consider the activity of water for lead is affected by the previous contact of the water with iron. For example, their experiments show that the solvent action of Loch Katrine water is reduced thereby to about $\frac{1}{15}$th of a grain per gallon. They add :—

The experiments above referred to are of the greatest practical importance, as they show that Loch Katrine water does not act upon lead under the circumstances in which it would be placed when used for the supply of a town.

The subject is not of much practical moment, seeing that iron mains are at the present time usually protected from the first by some form or other of coating, or acquire some sort of incrusting coating by use. Further, supposing the action on lead to be lessened, the protective influence implies contaminating the water with iron to such an extent as to render it unfit for washing, bleaching, and other purposes.

III.—Action of Distilled Water, and of Rain and Snow Water, on Lead.

a. *Distilled Water.*

On the authority of Medlock (*Record of Pharmacy and Therapeutics,* Part II., p. 34), perfectly neutral distilled water, free from nitrate or nitrite of ammonia, is without action on lead. He records that, on allowing 560 square inches of lead to remain for forty-eight hours in contact with such a water, he could discover no trace of lead in solution. If distilled water be saturated with oxygen, a piece of bright lead will after a few minutes' immersion, become coated with a white deposit of lead oxide. If distilled water be aërated with common air (containing carbonic acid), the lead will become speedily coated

with a grey deposit, the action being of short duration if the water be not exposed to the air, but continuous if it be freely exposed. Under both conditions the solution of a certain proportion of lead will be effected.

Labarraque and Pelletier, in 1830, on examining sundry orange-flower waters that had been preserved in copper bottles soldered with lead, recorded that they found lead in all the samples, independently of whether the bottles were quite or partially full. They accounted for the solution of the lead by a portion of the water having undergone acetous fermentation, a view afterwards adopted by Chevallier.

b. Rain and Snow Water.

It was noted many years ago that rain water, or the water produced from snow and ice, collected at a distance from human habitations, acted with greater energy on lead than rain or snow water collected in a town.

Christison records the following four experiments bearing on this point :—

(1.) *Country Rain Water.* [No precipitate with ammonic oxalate, nor with barium or silver nitrates.] 340 grains of bright lead rod immersed in 12 oz. of the water. Lead dulled in less than 1 hour. Lead lost 2 grains in weight after 8 days' immersion.

(2.) *Town Rain Water, collected from roof of house in Edinburgh at the end of half-an-hour's rain. No rain had fallen previously for several weeks.* [Distinct precipitate with barium nitrate; faint precipitate with silver nitrate; no precipitate with ammonic oxalate.] No action on lead.

(3.) *Town Rain Water (same as No. 2), but collected after 4 hours' rain.* [Faint precipitate with barium nitrate; no precipitates with silver nitrate nor ammonic oxalate.]—Action on lead slight. Three bright lead rods were immersed in 4 ozs. of the water. A crystalline powder collected on the bottom of the glass after 5 hours. Lead lost 0·02 grain after 9 days' submersion.

(4.) *Town Rain Water (same as Nos. 2 and 3), but collected after 24 hours of continuous rain.* [No precipitates with ammonic oxalate, nor with barium or silver nitrates.]—Action on lead as energetic as that of distilled water. Deposit on glass appeared within half an hour, 1·33 grains of lead being dissolved in 33 days. [The quantity of lead and water used not stated.]

Christison concludes, from these and other experiments, that it is dangerous to employ snow or rain water collected from new lead roofs or spouts, for culinary or drinking purposes. Nor does he think it safe to use rain water that has been in contact even with old lead; because, although the protective coating formed upon the metal prevents the action of distilled water, nevertheless the impetus of a heavy storm is sufficient to detach portions of the crust, and so expose a fresh surface of lead to the water; whilst the action of water containing acid vapours in solution (such acid vapours being certain to be dissolved specially by the first rain that falls in a town) is capable of effecting the rapid destruction of the protective covering.

The possibility of an accident arising from such cause is illustrated

by an outbreak of lead colic that occurred at Amsterdam in 1757, no similar attack having been recorded previously to that year. (Tronchin, *De Col. Pict.*) This outbreak coincided with the general substitution of lead for tile roofs in the town. Tronchin does not appear to have been aware of the action of pure rain water on lead; but he lays stress on the fact that the outbreak of lead poisoning occurred in autumn, and he accounts for it by the rain water acquiring acidity from the decay of the leaves that collect on the house roofs at this period of the year, which acidity assisted, in his judgment, the solution of the lead.

Christison refers to two other cases, similar to the Amsterdam case, the one occurring at Haarlem [recorded by Wanstroostwk, and referred to by Mérat (*De la Colique Metallique*, p. 99.)], and a second at Manchester. In this latter case, the rain water from a leaden roof had been used as a potable supply for nine years, without causing any toxic effects. Suddenly cases of lead poisoning resulted from its use, when it was found that the rain water had become impregnated with hydrochloric acid, the vapour of which, it was proved, was evolved from an adjoining factory. [Christison does not record how recently this factory had been in operation, nor the amount of lead dissolved by the water, beyond stating that a black precipitate was produced when the water was treated with sulphuretted hydrogen.]

It may not, however, be correct to attribute all the changes in a lead roof, or in a cistern, to the action of water, seeing it has been shown that riddled holes in lead may be caused by the larva of an insect (*Callidium bajulus*), in the stomach of which lead is often found (Kirby and Spence, *Entomology*, I., p. 235).

Faraday, in reporting on the rapid action on lead of the ice water yielded by Wenham Lake and Norwegian ice, mentions it as a proof of its great purity. He warns people, however, that on this account it is dangerous to preserve Wenham ice in refrigerators lined with lead (*Medical Gazette*, July 19, 1850, p. 130).

IV.—Special Opinions on the Action of Water on Lead.

We propose now considering the views that have been held by authorities, respecting the cause of lead poisoning by water, under the ordinary conditions of its supply.

Lead conduit pipes have been used for the conveyance of water from very early times. It is said that the Appian aqueduct was constructed of lead (Varro, B.C. 116). Vitruvius, a Roman architect, who lived in the time of Cæsar and Augustus, was the first to draw attention to the dangers incident to its use. (Vitruvius, *De Architectura*, L. viii., c. 7: "Quæ modis ducantur aquæ." Ed. Dan. Barbari, 1567, pp. 262-5.) "Water," says Vitruvius, "conducted through earthen pipes is more wholesome than through lead; indeed that conveyed through lead must be injurious to the human system. Water

should therefore on no account be conducted in leaden pipes, if we are desirous that it should be wholesome." The remains of many Roman works disclose an earthenware distributing apparatus.

Galen, many centuries ago, described the dysentery to which people were subject, who drank water after it had been permitted to remain in contact with lead.

The following are the principal investigators of later times :—

Dr. Lambe, of Warwick (*Researches into the Properties of Spring Waters*, 1803) notes that spring waters generally dissolve (corrode) lead, so as to render the water unfit to be used for drinking. He accounts for this solvent property of the water by the presence of certain saline ingredients in solution.

Guyton Morveau (*Annales de Chim.*, lxxi. 197, 1809,) records that the purest water he could prepare (viz., distilled water) acts rapidly on lead, by converting it into a hydrated oxide, whilst certain natural waters, owing to the presence of soluble salts, hardly attack lead at all. Discussing at some length the cause of this non-action in the case of certain waters, he attributes it to the presence of earthy sulphates.

Thomson, of Glasgow, (his experiments being recorded in "*Scudamore's Analysis of Tunbridge Water*," 1816,) describes in detail the corroding action of spring waters on lead. He maintains that the lead is not dissolved, but merely mechanically suspended in the water, the quantity so suspended being never sufficient to prove injurious to the habitual water drinker.

It may be worth noting here that Marshall Hall, in the "*Quarterly Journal of the Royal Institution*," 1819, published a memoir on the combined agencies of oxygen and water on the oxidation of iron, showing that water freed from oxygen had no action on the metal.

Captain Yorke (*Philosophical Magazine*, Third Series, v. 81, 1834) considers that when water is fully saturated with lead, the quantity may amount to 7 grains per gallon. The solvent power of water for lead is in his opinion chiefly dependent on the presence of free carbonic acid. He gives the analysis of the dried white deposit on the lead as follows :—

Oxide of Lead	87·9
Carbonic Acid	8·6
Water	3·5

Hence he concludes that the deposit formed is a compound of hydrated oxide and carbonate of lead.

Professor Daniel, of King's College, (in a letter to Mr. Morson, *Pharmaceutical Journal*, 1842-43, p. 355,) records that independently of lime and other salts, water containing free carbonic acid readily dissolves lead, and cannot therefore be safely preserved in lead vessels or be transmitted through lead pipes.

In a letter to the *Pharmaceutical Journal*, 1842-43, p. 406, Mr. Ince records that, having occasion to note the action of distilled, of river, and of various spring waters on clean iron filings, on lead, and on copper respectively, he found

that a notable quantity of each metal was dissolved after some days, but records that " the well water, which contained a large quantity of lime salts, had by far the most solvent power."

So far as spring waters are concerned, the early experimenters noticed the occurrence of exceptions to the general rule that lead was not affected by them. Dr. Lambe even imagined that every spring water dissolved sufficient lead to act injuriously.

To Sir Robert Christison we are indebted for the first carefully conducted experiments,—these being made with special reference to the action upon lead of the Edinburgh water (1845). The composition of this water he gives as follows :—

Total Solids	...	...	...	...	5·83 gr. per gallon.
Carbonate of Lime	...	...	...	3·88	,,
Sulphates and Chlorides (by diff.)	...	1·95	,,		

The following experiments, amongst many others, are recorded :—

EXPERIMENT 1.—Three bright lead rods, weighing 57 grains, were immersed in 4 ozs. of water :—

	Lead bars lost weight.	Results.
After 7 days	$\frac{1}{150}$ gr.	{ Lead hardly tarnished. No speck of powder visible in water or on glass.
,, 21 ,,	$\frac{1}{100}$ gr.	
,, 35 ,,	$\frac{1}{60}$ gr.	Lead uniformly dull. On the surface of water, on bottom of glass, and on the sides left dry by evapo-
,, 63 ,,	$\frac{1}{59}$ gr.	ration, white specks, turning black when touched with ammonic sulphide, were visible.

EXPERIMENT 2.—145 grains of lead were kept for 6 months in 6 ozs. of Edinburgh water. The bottle was filled up as the water evaporated. The lead lost $\frac{1}{15}$th of a grain, the bottom and sides of the glass becoming covered with a white incrustation.

From these experiments he concludes :

1. That inasmuch as water rarely remains in the lead pipes or in lead cisterns for more than one day, whilst the quantity of lead dissolved after " a few days'" contact was " so small as to be barely perceptible by the nicest analysis," that leaden cisterns and service pipes may safely be used for the Edinburgh water.

2. But that if the same portion of water be kept in lead for a considerable length of time, the impregnation with lead may be material. Thus he records that having on one occasion permitted a layer of about six inches of Edinburgh water to remain in the leaden cistern of his laboratory undisturbed for four or five months, he found a large quantity of crystals of lead carbonate lying loose in the cistern, whilst the water was opaque from the lead in suspension. [Mérat states that he obtained two ounces of carbonate of lead from about 100 gallons of water after keeping it for two months in a leaden pneumatic trough.] (See Cases.)

On the other hand, Dr. Thomson, of Glasgow, records that, when living in Edinburgh some years prior to 1815, he could always detect a trace of lead suspended in the water delivered at his house (which, however, was not the Crawley spring water in use in 1845), the water supplied at that time being brought to the city, from a distance of six miles, in leaden pipes. " I

presume," says Christison, in criticising this statement "it is owing to the main pipes being now made of iron that this impregnation no longer exists."

Sir R. Christison further deals with the action of water on lead in the *Pharmaceutical Journal* of April 20, 1872, p. 852, and of July 19, 1873, p. 47.

He explains the non-action of spring waters on lead, on the ground that " they usually contain a considerable proportion of muriates and sulphates."

In a paper in the *Pharmaceutical Journal*, 1844-5 (p. 203), Crace Calvert notes that acting on bright lead with distilled water and with R. Seine water respectively, the lead in the distilled water rapidly tarnished and became covered with a white deposit, whilst the water after a few minutes became milky, and contained a notable quantity of lead. No such changes occurred with the Seine water. He then describes a series of experiments, and concludes : " The nature and quantity of the salts contained in waters exert considerable influence on the proportion of lead which the waters are capable of dissolving. After the above observations I am satisfied that the action of water on lead depends principally on the quantity of salts which it contains. Likewise there must exist a ratio between the quantities of salt and of water, in order that the action of the latter may be at the minimum, so that there is a limit where the water containing determinate proportion of salt of the same nature or of different composition must exert its minimum effect. Thus these limits and relations being once raised, or fallen short of, the action of the water increases, and is capable of becoming charged in greater quantity with soluble compounds of lead."

Crace Calvert, in a second paper read before the British Association (1862), records observations on the action (amongst others) of the Manchester supply on lead. He states that upon allowing the Manchester water to run through a new lead pipe, he found it highly charged with lead compounds, even at the end of four days. The contamination decreased during the succeeding six weeks, after which the water ceased to take up lead. But he records that if the water during this period was allowed to remain in contact with the pipe for 12 hours, it would still take up as much as 0.2 gr. of lead per gallon. But after three months, from 12 hours' contact it absorbed only 0.033 gr. per gallon.

Calvert also made experiments on Manchester water with lead-, with tin-, and with tinned-lead pipes, the water being allowed to remain in contact with the several specimens for 12 hours.

The results were as follows :—

No. 1. Extra tinned-lead piping	...	...	⎫
„ 2. Ordinary do.	...	...	⎬ Water dissolved from 0.1 to
„ 3. Best or virgin lead piping	...	...	0.3 gr. of lead per gallon.
„ 4. Common lead piping ...	...	...	⎭
„ 5. Block tin piping	...	...	... No action on the metal.

Calvert considers that from 0.1 to 0.3 gr. of lead per gallon is likely to prove dangerous, and states his knowledge of cases where injury has resulted from these quantities.

Lastly, he records that, on allowing water to remain for some time in the pipes, and then again bringing them into constant use, the action of the water on the pipes was greatly increased.

In the discussion on Dr. Calvert's paper, Dr. Angus Smith referred to serious lead poisonings, and even to deaths, which had occurred from drinking Manchester water. As little as $\frac{1}{40}$th grain of lead per gallon would, in his experience, be injurious to some people.

Crace Calvert (*Chemical News*, 1865, p. 172) has further shown that sea water has practically no action on lead. He gives the following table as the result of his experiments, where in each case 100 litres of sea water was allowed to act on one square metre of the several metals named :—

	Quantity of metal dissolved. Grammes.
Steel	29·16
Iron	27·37
Copper (best selected)	12·96
„ (rough cake)...	13·85
Zinc	5 66
Galvanized iron	1·12
Block tin	1·45
Stream tin	1·45
Lead, Virgin	trace
„ common	trace

Mr. Richard Phillips, jun., (*Pharmaceutical Journal*, 1844-5, p. 304,) published a paper on " The Action of Lead on Distilled and River Water." He agrees with Christison, that the rapidity of solution when lead is only partly immersed in water is greater than when it is entirely submerged. He further agrees with Christison that lead is not soluble in distilled water, deprived of, and out of contact with, air. He details experiments, however, to show, that if the water be first boiled, and when cold put into a bottle (the bottle being perfectly filled) and a piece of lead be added, then although the lead remains bright, a certain quantity of lead is dissolved. He considers this due to the water having absorbed air on cooling. He agrees with Colonel Yorke as to the composition of the deposit formed when lead is acted upon with distilled water, except that he considers the deposit to be a mechanical mixture of the carbonate and hydrated oxide, and not as Yorke supposes, a precipitate of definite composition. As regards, however, the lead in solution, he differs from him, believing that whatever lead is in the water is merely the oxide in a condition of fine sub-division. He bases this opinion on the fact that by passing the water through a paper filter, it is deprived of its lead.

He further describes a series of experiments on water from the Thames. He ascribes the non-action of Thames water on lead to the presence of sulphate of lime. He disagrees with Christison as to the protecting influence of chloride of sodium in the water, but agrees with him as to the power of sulphate and carbonate of lime. He suggests that Christison's experiments may have been made with a chloride containing a small quantity of sulphate.

Criticising Christison's results with rain water, to the effect that whilst the

first rain did not act on lead, the rain which fell after some time did act, owing, as Christison supposed, to certain earthy ingredients having been taken up by the first rain, Phillips records his experience that carbonate of ammonia has a great power in protecting lead from corrosion.

Colonel Yorke (*Memoirs of the Chemical Society,* and *Pharmaceutical Journal,* 1845-46, p. 279) in reply to Mr. Phillips' statement that the lead oxide was merely mechanically suspended in the water, admits that filter paper retains the oxide. He records, however, a series of experiments which show that paper, in common with porous bodies and organised fibres generally, separates certain substances from solution, and lead amongst the number. Thus Mr. Crum notes that cotton wool has the power of abstracting lead oxide from its solution in lime water, and that this property is made available in the processes for dyeing cotton with the chromates (*Philosophical Magazine,* April, 1844). Further, Colonel Yorke points out that after the fibres of the paper have become saturated with the lead oxide, the dissolved lead readily passes through. It would, therefore, be unsafe to trust for an unlimited time to the action of a filter to separate lead oxide from water.

In a paper by Dr. John Smith, M.D., of the University of Aberdeen, read before the Chemical Society, April 7th, 1851 (*Pharmaceutical Journal,* 1850-51, p. 568), he records having made about 40 examinations of Dee water, after its passage through lead pipes varying from 12 to 100 yards in length. In some cases lead was found to the extent of from $\frac{1}{100}$th to $\frac{1}{20}$th gr. per gallon. Dr. Smith, from inquiries, concludes, " that less than $\frac{1}{20}$th gr. of lead per gallon produces no deleterious effect upon the health of those using the water for dietetical purposes, and that the limit of the deleterious action is between the $\frac{1}{10}$th and $\frac{1}{20}$th of a grain of lead to the gallon of water."

The effect of various saline compounds in a water, so far as relates to its action on lead, has been studied at considerable length by M. Fordos (*Journal de Pharmacie et de Chimie,* July, 1874). He states that in potable waters containing bi-carbonate of lime, a precipitate of the mixed carbonates of lead and lime adheres to the lead pipe, but that if alkaline sulphates or chlorides are present in the water, then it becomes contaminated with dissolved lead to an injurious extent. Thus he says, " The presence of alkaline salts in water renders partially soluble those lead salts which are insoluble in pure water (as the sulphates and carbonates), and thus partially counteracts the beneficial effects of the earthy sulphates and carbonates in preserving the pipe from being further acted upon by the water." This view was afterwards adopted by Thomas Spencer.

Dr. Lauder Lindsay, of Perth, at a meeting of the British Association, described his experiments on the action of hard waters on lead (Chemical Section, September 24, 1858). (See the *Edinburgh Philosophical Journal,* April, 1859.) He defines a hard water as one containing an appreciable amount of lime or magnesia sulphates, carbonates, and chlorides, accepting Christison's view that a water is to be regarded as " soft " that contains less than $\frac{1}{5000}$th part

of its weight of saline ingredients, "hard" if it contains over the $\frac{1}{4000}$th, and "mineral" if over the $\frac{1}{2000}$th. His general conclusions may be thus tabulated :—

(1.) Under certain circumstances pure or soft waters do not act on lead. Thus he states that some pure and soft waters (containing under 2·25 grains of solid matter per gallon, and with a hardness of 0·8°) exert no deleteriously solvent action.

(2.) That certain hard waters, containing an abundance of the very salts generally regarded as protective, do act on lead.

Of spring waters which act with dangerous rapidity, several instances are quoted.

Dr. Lindsay thinks Dr. Lambe's view "that all waters act on lead" is a safer and more accurate one than the modern idea that small quantities of certain neutral salts act as preventives. Lindsay records that—

(a.) Corrosion of lead cisterns has occurred within his experience by waters containing all varieties and amounts of neutral salts, and of very various, and in some cases, of very considerable degrees of hardness.

(b.) Lead poisoning has occurred in his experience from the action of hard waters so impregnated. Of these he gives several instances.

(3.) That in these exceptional cases, the action of certain hard waters, and the non-action of certain soft waters on lead, is very imperfectly understood.

(4.) That the conclusions drawn from experiments on a small scale and for short periods are often very fallacious.

(5.) That water may contain a considerable amount of lead without acting injuriously on the majority of people, whilst a small quantity may in certain exceptional cases act deleteriously both on man and on animals.

(6.) That the use of a lead water is the obscure cause of many anomalous colicky and paralytic affections.

Dr. Lindsay says that his remarks are only intended to be suggestive, " the fact being that the rationale of the non-action of certain soft waters and of the action of certain hard waters on lead is very imperfectly understood," the whole subject being in an unsatisfactory state.

As an illustration of the unsatisfactory condition of our knowledge, Dr. Medlock (*Record of Pharmacy and Therapeutics of the General Apothecaries' Company*, Part II., p. 33, 1857), records an examination of three waters made by the late Dr. Noad. No. 1 was from a deep well near Highgate Churchyard, containing 100 grains of solids per gallon, of which 57 grains were nitrates of lime and magnesia. No. 2 was from a spring at Clapham, containing 77·74 grains of solid matter, of which 4·1 grains were organic, the remainder consisting of salts of lime, magnesia, potash, and soda. No. 3 was a deep well water in London, containing 68 grains of solids per gallon (chiefly potash and soda salts) with very little lime carbonate or organic matter. He found all three to act on lead freely; attributing the action in No. 1 to the nitrates, in No. 2 to the organic matter, and in No. 3 to the free alkali.

The action of water on lead pipes was again the subject of a communication to the Academy of Science by M. Belgrand (Nov., 1873). He estimates that the total length of lead piping in Paris is 1,580,000 mètres. After a short time the pipes become firmly and rapidly coated with a thin smooth crust of carbonate of lead. Several samples of Paris water (R. Seine), drawn through pipes from 40 to 200 mètres long, were examined, but no lead was found in them. A series of experiments were conducted with the Paris water by M. Le Blanc, who records that its action on lead is practically *nil*. M. Le Blanc notes that chemists generally attribute this to the presence of salts in solution, but admits difficulties in accepting this view as a complete explanation of the facts. He refers to lime salts as specially valuable, but states that in their absence other salts also possess protective powers. Thus, he records experiments with solutions of sulphate of soda, chlorides of sodium and potassium, and sulphate of magnesia (0·1 grm. per litre) all of which act on lead for periods of about twenty-four hours, after when the solvent action ceases. M. Belgrand considers that there is no danger of poisoning from the use of Paris water flowing through lead pipes, and is opposed moreover to the use of tinned lead conduits.

It is worth noticing that an outcry, as to poisoning from the use of lead pipes as water carriers, has occurred not only in Paris, but also in Brussels (water 18° of hardness), the water being derived from the chalk ; at Lisbon (water 3° of hardness) ; and at Avallon (water 2° of hardness). The water in the last case is derived from the granite formation ; and on careful inquiry no instances of well-proved ill effects from its use could be obtained.

The action of water on lead was a subject-matter of grave importance in 1854, when the supply of Loch Katrine water to Glasgow was first proposed. We deem it right to refer to the investigations made at the time in some detail. Dr. Miller, in his report upon the subject, gives the analysis of Loch Katrine water as follows :—

Silica	0·16 grs.
Sulphate of lime	0·56
Chloride of calcium	0·16
Common salt	0·29
Carbonate of magnesia	a trace.
	1·17 grs.
Hardness ... ... 0·6 degree.	

He remarks :—

This water has a more remarkable action upon lead than any natural water I have had occasion to examine.

He compares it for example to the Dee water, the action of which on lead is very unimportant. He gives a detailed analysis of the Dee water at Aberdeen as follows :—

Silica	0·50 grs.
Carbonate of lime	0·84
Sulphate of lime	0·19
Sulphate of magnesia	0·32
Chloride of sodium and potassium	0·82
Oxide of iron and phosphates	0·10
Loss ... ... 0·06	2·83 grs.
Hardness... ... ... 1·4 degree.	

He concludes his report as follows:—

1st. The water of Loch Katrine acts dangerously upon lead whether the metal be in the form of sheet, such as is used for cisterns, or in that of pipe, whether new or previously used for conveying water, like that of the Clyde.

2nd. The waters of the Dee at Aberdeen, and of the Tay at Perth, have, under ordinary circumstances, no dangerous action upon lead, though even these may at times dissolve the metal to an unsafe extent.

My experiments, however, do not enable me to say whether such action on lead will be modified or affected by changes produced upon the waters by changes of season; and my remarks must therefore be regarded as applicable with certainty only to the sample and the season to which they refer.

Mr. William Wallace, of Glasgow, gives the following as his conclusions (re the action of Loch Katrine water on lead), based on numerous experiments :—

1st. That Loch Katrine water acts most energetically upon lead, more especially upon new lead, no matter whether it be clean and bright, or in the state in which it is procured from the plumber; whether exposed to the rays of the sun or kept in total darkness; and whether air is freely admitted or altogether excluded.

2nd. That in open vessels, with free access of air, a large amount of a light, pearly crystalline precipitate is formed, consisting of the hydrated oxide of lead combined with variable proportions of carbonate of lead—a small quantity only remaining in actual solution.

3rd. That this action goes on continuously for days, weeks and months, and appears in fact to be without limit; and that when a piece of lead which has been immersed for a long time in the water, is transferred to a fresh quantity, the action immediately commences and goes on as before; and therefore, that the Loch Katrine water does not possess the power of coating lead so as to prevent further action.

4th. That in closed vessels the action, although neither so rapid nor so extensive as in those to which air is admitted, is yet of a most dangerous nature, a very large amount of oxide of lead being held in actual solution. This effect is the more dangerous, as the presence of the lead thus existing in solution is not detected by mere inspection, and is only revealed on the application of the appropriate chemical tests.

5th. That many other soft and pure waters, used as sources of supply, do not possess the same property of dissolving and corroding lead to such an alarming extent, and therefore that the Loch Katrine water cannot be compared with them.

Dr. Penny, Professor of Chemistry in the Andersonian University, Glasgow, having given the results of his experiments on the action of water on lead, remarks :—

It is no part of my present duty to explain the *causes* of the action of Loch Katrine and other waters on lead, or to enter upon the discussion of the various circumstances by which it is increased or diminished, promoted or retarded. In the case of Loch Katrine water, however, I may briefly explain that, in open vessels, the lead is oxidised by the oxygen gas dissolved in the water; the oxide of lead thus formed dissolves in the water, and then absorbing carbonic acid from the atmosphere, separates in pearly scales, consisting of the hydrated oxide and carbonate of lead, with a little organic matter. Notwithstanding the many researches that have been made, our knowledge of the conditions that influence the corrosive and solvent action of water on lead, is extremely limited. On taking a retrospective glance of the history of the subject, it is not a little curious to observe how suddenly and frequently the views of chemists have oscillated and changed. At one time it was maintained by Lambe, Thomson, and others, that spring waters were most powerful in corroding lead. Guyton Morveau, Christison, and others, on the contrary, who pursued their investigations in a more comprehensive and scientific manner, arrived at the opposite conclusion, and inferred, speaking generally, that the corrosive influence of the water was in direct proportion to its purity; and that certain saline ingredients in spring water were a means of preventing its action on lead. These contradictory views have been more than once revived and discussed. Our acquaintance with the actual circumstances that retard or accelerate the action is in an equally unsatisfactory state. At one time soluble sulphates and phosphates were regarded as the most powerful protecting agents, and nitrates and chlorides the most active saline promoters. At another, waters which are alkaline, and those which contain a notable quantity

of organic matters, and of carbonic acid gas, were considered to be most energetic in their corrosive powers. At the present time some authorities affirm that alkaline carbonates and phosphates are most effectual in destroying this action of soft and pure waters ; and very recently, in the case of Loch Katrine water, a touch of the " old red sandstone, and the carbonic acid and carbonate of ammonia of the atmosphere," have been ranked among the curative agents. In a word, we have no fixed or satisfactory principles for our guidance. The whole subject stands much in need of careful and comprehensive research ; and until this research has been made, we must be content to make a specific examination of the qualities of each water in relation to lead, and to judge it upon its own merits, independently of pre-conceived notions and speculations.

He further records :—

It is my decided opinion, that *lead immersed in Loch Katrine water does not become covered in the course of a few days with a thin coating that prevents all further corrosion ; and that it does not, even when kept in the water for six weeks, resist the action of a new quantity.*

And again he says :—

Loch Katrine water, therefore, acts upon lead piping that has for many years conveyed the present Glasgow water.

In the case of Loch Katrine water it was proposed, in order to meet this difficulty, to bring it to Glasgow through a conduit constructed partly of old red sandstone and partly of limestone. On this Dr. A. S. Taylor reports :—

That the Loch Katrine water, which has been placed in contact with old red sandstone and limestone, obtained from the district which it was proposed that the water should traverse, has no action on lead. The water dissolves a small quantity of salt and carbonate of lime ;— these substances protect the surface of the metal from further chemical action.

Upon this point Dr. Anderson and Mr. Dugald Campbell jointly report :—

But the experiments at the Trossachs do not completely fulfil the conditions under which the Loch Katrine water will be carried to Glasgow. In addition to iron and leaden pipes, it will be conveyed through many miles of a conduit built principally of the old red sandstone of the district, and in one place crosses a thin bed of limestone. Being aware that it frequently happens that though the water of a lake may act strongly on bright lead, the stream which flows from it, if examined some miles below its point of exit, is without action —a change manifestly due to the rocks and pebbles of which its bed is composed—we have examined the action of the old red sandstone and limestone on Loch Katrine water. By repeated experiments we have ascertained that when the Loch Katrine water is allowed to stand for 10 or 12 hours over fragments of the old red sandstone, of which the conduit will be made, that the action upon bright lead is so greatly diminished, as to be barely appreciable, and upon lead in its ordinary state no action whatever could be detected, on applying the most delicate tests.

The limestone produces a similar effect, but its influence is of much less importance, as it forms only a thin bed with which the water is in contact for a very short time. With the sandstone, however, the water will be in contact for a considerable period, as we are given to understand that it is the material of which the greater part of the conduit will be built, and the time of flow through it will be about 10 or 12 hours. It cannot, therefore, be doubted that during its passage through it, the water will necessarily be deprived of all power of acting upon lead as exemplified in our experiments. In other respects it will be little changed, and will still be a water of remarkable purity for all purposes. We find the solid contents, per gallon, after standing for 12 hours in contact with the sandstone, to be 3·02 grains, and the hardness 1·9 degrees.

And again :—

By standing in contact with the old red sandstone, of which the conduit will be made, the Loch Katrine water almost entirely loses its action on bright lead.

In their report, the Glasgow Corporation, dealing with this suggestion, mention that :—

Many of the rivers, after flowing out of lakes, the water of which has violent action on lead, and which pass over sandstone or other neutralizing geological formations, have been traced down, to ascertain how soon and from what apparent cause the water is deprived of its power to act on lead. Among these are the Eamont, flowing out of Ullswater; the Derwent, out of Bassenthwaite Water; the Dee in Wales, out of Bala Lake; the Tay, out of Loch Tay; and the Teith, from Loch Katrine. The Eamont loses its action very soon after leaving the lake, upon entering a limestone district. The Derwent, which flows over the slate rocks of the Cumbrian formation, retains its action to near Cockermouth, where it enters limestone. The Dee, from Bala Lake, retains its action to a considerable extent till mixed with water from the Caradoc sandstone; and the Tay, till after running for some distance over old red sandstone. The Teith, which passes over this formation when it leaves Loch Vennechar loses much of its power before it joins the Forth, though, in consequence, probably, of the large body of water, and the gravel which prevents any close contact with the softer beds of sandstone, the action is not as much diminished as in other cases.

Upon this question Dr. Penny, who gave evidence against the Bill of the Promoters, says :—

For my own part, I believe it quite possible to bring Loch Katrine water to Glasgow as pure and soft as it is in the Loch; and, on the other hand, I think it would be quite easy by *doctoring* it on its journey, as proposed in the Promoters' Evidence, to change its qualities completely, and, by increasing its degree of hardness, to deprive it of its present vexatious power of corroding and dissolving lead.

Dr. R. D. Thomson, of St. Thomas's Hospital, to whom this question was referred, reports as follows :—

The experiment was made by us of agitating Katrine water in contact with the old red sandstone in a broken state, and afterwards exposing this water to lead. The water retained its great original softness, but lost entirely its action upon lead. We infer, therefore, that the Katrine water would speedily lose its power of acting upon lead, by passing through channels composed of the old red sandstone rock such as it is proposed to construct for the conveyance of the water to Glasgow.

A similar experiment was made by substituting for the red sandstone the mountain limestone of the Loch Katrine district. The hardness of the water was increased from one degree to three degrees, while the power of the water to act upon lead disappeared entirely as in the previous experiment with the old red sandstone. Hence the employment of this rock in the construction of the conduits, or its presence merely in broken pieces in the bed of the stream, would insure an entire immunity to the water from subsequent contamination with lead.

He further reports :—

The power of acting upon lead of both distilled water and of Katrine water for twenty-four hours was destroyed by the addition of 1-50,000th part of carbonate of lime (chalk).

The water was equally prevented from acting upon lead by the addition of 1-20,000th of the following substances :

Bicarbonate of ammonia.	Bicarbonate of soda.
Carbonate of soda.	Phosphate of soda.

With the same small proportion of sulphate of soda, ammonia, and lime, the metal was considerably corroded by the water, but the proportion of lead actually dissolved within a short period, such as 24 hours, was much less than is dissolved in pure water.

The substances which give the greatest amount of protection to water from the action of lead are of an alkaline character, such as soluble carbonates and phosphates; but free carbonic acid also in a proportion not exceeding 1 per cent. gives a temporary protection, extending to 12 or 24 hours, probably due to the extreme insolubility of the carbonate of lead.

It is to be observed that several of these protecting substances may often be obtained by water from the atmosphere, such as carbonic acid and carbonate of ammonia, or from the soil and rocks over which the water passes, such as carbonate of lime, and occasionally carbonate of soda.

It is also evident that no soft water intended for a town supply need be allowed to remain with the power to act upon lead, seeing that the utmost degree of safety may be obtained by allowing the water to come in contact with carbonate of lime.

The action of water on lead became a question of serious inquiry when the Croton water was first introduced into New York. Probably, however, it was more fully inquired into at Boston (U. S. A.), in 1859, when the supply of the Cochituate water was proposed, than at any other time. In a report by the Consulting Physicians of Boston, they remark with respect to the Cochituate water :—

1. That lead, received into the body, in certain quantities and for a certain time, is liable to produce some alarming complaints, among which are a species of colic, and a species of paralysis. 2. That most of the natural waters, which are introduced through pipes into the cities of this country, and probably of Europe, are capable, under certain circumstances, of dissolving lead. 3. That notwithstanding these general facts, a large portion of the population of Boston, Philadelphia, New York and London, have for years consumed the water introduced from various sources through leaden pipes, with apparent impunity.

A series of experiments was undertaken to determine the extent of the action of this Cochituate water. The physicians referred the following question to Professor Horsford :—

Will there be greater liability to lead disease from drinking Cochituate water served through iron mains and leaden pipes, than there is now from drinking Fairmount or Croton waters similarly served, or Jamaica water possibly less favourably served than Cochituate water will be?

Professor Horsford's report is an elaborate one, and it is only possible to record the following summary of his conclusions :—

(*a.*) Lead is not oxidated in dry air, or (*b.*) in pure water deprived of air. (*c.*) It is oxidated in water, other things being equal, in general proportion to the amount of uncombined oxygen in solution. (*d.*) When present in sufficient quantity, nitrates in neutral waters are, to some extent, reduced by lead. (*e.*) Both nitrates and chlorides promote the solution of some coats formed on lead.

(*f.*) Organic matter influences the action of water upon lead. If insoluble, it impairs the action by facilitating the escape of air; if soluble, by consuming the oxygen in solution, and by reducing the nitrates when present. The green plants, so called, and animalculæ, which evolve oxygen, are abundant in open waters in warm weather only, and of course when the capacity of water to retain air in solution is lowest; so that, although oxygen is produced in open waters by these microscopic organisms, it does not increase the vigour of their action upon lead.

(*g.*) Hydrated peroxide of iron (iron-rust) in water is not reduced by lead. Hence may be inferred the freedom from corrosion of leaden pipes connected with iron mains, so far as the reduction of the pulverulent peroxide of iron may influence it.

(*h.*) Alkaline chlorides in natural waters deprived of air do not corrode lead. (*i.*) Salts generally, impair the action of waters upon lead, by lessening their solvent power for air, and by lessening their solvent power for other salts.

A coat of greater or less permeability forms in all natural waters to which lead is exposed. The first coat (*j.*) is a simple suboxide absolutely insoluble in water, and solutions of salts generally. This becomes converted in some waters into a higher oxide, and this higher oxide, uniting with water and carbonic acid, forms a coat (*k.*) soluble in from 7,000 to 10,000 times its weight of pure water. The above oxide unites with sulphuric and other acids which sometimes enter into the constitution of the coat (*k.*);—uniting with organic matter and iron-rust, it forms another coat (*l.*) which is in the highest degree protective. The perfection of this coat, and of the first above mentioned, may be inferred from the small quantity of lead found in Croton water (New York), after an exposure in pipes of from twelve to thirty-six hours, and from the absence of an appreciable quantity in Fairmount water (Philadelphia), after an exposure of thirty-six hours, when concentrated to one-two-hundredth of its bulk.

An interesting series of experiments is recorded on the action of Cochituate water to which various quantities of Tannic Acid had been added. It is noted that—

The influence of increased organic matter of this form, Tannic acid (which is as nearly allied to the vegetable matters that might be expected to occur in lake water as could be readily

found) was to lessen the action on lead. [And again :—] It has been conceived that organic matter might exert a deleterious influence. Experiments, already recorded, show that the presence of organic matter increases the protecting power of water which is to be transmitted through lead. If the quantity exceed one-ten-thousandth of the weight of the water, precipitates of oxide of lead, united to organic matter, take place.

The physicians, to whom the whole subject was submitted, report :—

It is by no means certain that minute quantities of lead, even when received into the human body, do occasion the injurious effects which result from larger quantities. In the ordinary conditions of civilised life, very few persons can hope to escape so receiving them. Lead is present in the paint of houses, and in that of buckets and other receptacles of water. It is contained in the solder of tin plate vessels, and in that of water pipes of various metals. It is used to make tight the joints of iron mains in large aqueducts. It helps to form the cheap pewter of which spoons, plates, and other culinary vessels are made. It is present in the glazing of the coarsest pottery, and in the finest flint glass. It affords the lining of tea chests, and often the coloring material of wafers and other common substances. It is carried through life in the bodies of wounded soldiers, and is applied in various forms by surgeons and physicians, to recent wounds and absorbing surfaces. It is also administered internally as a medicine. The continual liability to mechanical attrition or chemical solution which exists in these cases, while it goes far to establish the inactivity of lead in certain minute quantities, should nevertheless put the community on their guard against the reception of larger quantities, through carelessness, of this and of other metals deleterious to health.

Their investigations, also, have brought them to the belief, that notwithstanding the attention which has been paid to the action of water upon certain metals, in different parts of the world, yet the subject is by no means satisfactorily understood. And they trust that more light may be shed upon it, after the conclusion of a course of observations and experiments now in process of being made by Professor Horsford, of the University.

In a report by Dr. Horatio Adams, of Waltham, Mass., on the action of water on lead, he states that oxide of lead is soluble to the extent of eight grains per gallon in distilled water, and adds :—

The influence of salts in causing oxide of lead to be dissolved by water is very unequal. Nitrates increase the solubility in a greater degree than do other salts. Sulphates and silicates alone do not dissolve oxide of lead.

Oxidation of lead and solution of the oxide in water are independent of the degree of hardness; hence the hardness being equal, oxidation may be very unequal. This seems, however, dependent on the quantity present of some particular salts, for a large amount of one salt renders lead soluble, when a smaller amount renders it insoluble. Hence, though the total of hardness may be equal, the solvent power may be very unequal. It may, however, be stated generally that salts causing hardness usually dissolve oxide of lead.

As regards the amount of lead that may exist in water without detriment to health, he remarks :—

We have yet to learn upon what facts, by what experiments this minimum has been placed by those eminent chemists, Professors Hofmann, Graham, and Miller (see Report on the Supply of Water to London, *Quarterly Journal of Chemistry*, No. 16), so high as one-fifty-seventh of a grain of lead per imperial gallon of water. "So minute a trace of lead," continue the above-named chemists, "remaining in the water could have no possible influence on the health;" and they seem disposed to adopt, if they do not in fact adopt the opinion of Dr. John Smith, of Aberdeen, "that less than one-twentieth of a grain of lead per gallon produces no deleterious effect on the health of those using it for dietetical purposes."

In numerous cases of well-defined, unmistakable lead disease, which have come under the observation of some of the members of the committee, the water suspected to be the cause of disease has been chemically examined. While, generally, it may be said that the amount of lead in solution would not fall below one-twentieth of a grain per gallon, yet, the cases have not been rare, where disease has been produced by less than one-one-hundredth of a grain of metallic lead per gallon in solution, or one in seven millions of water. One-hundredth of a grain of lead is easily detected by a simple stream of sulphuretted hydrogen. Water has sometimes caused disease, under the eye of a part of your committee, where this test showed no trace of

lead : yet, lead was abundantly evident after concentration of the water, and the sulphuret thus obtained has been converted into salts of lead, which have been again examined to confirm the hydrosulphurous test. Small as the amount of lead—less than one-seven-millionth of the weight of water—in solution thus appears, the committee are disposed to place it still lower. The Tunbridge well may be adduced, whose water, flowing through a lead pipe, disordered many who drank it; and it contained so minute a trace of lead in solution, that some of the most acute and eminent chemists of the day, men full of chemical tact and laboratory experience, failed to detect its presence. Happily for the afflicted, lead was at last detected, the pipe was removed, and health returned.

It is necessary that we should refer to the report of T. Graham, W. A. Miller, and A. W. Hofmann on the supply of water to the metropolis, wherein, after giving detailed analyses of the water, they remark, " *re* Lead ":—

The water at present supplied [to London] may be circulated through leaden pipes, or preserved in leaden cisterns, with an unusual degree of safety. The corrosion of water cisterns in London is generally occasioned by the mud which subsides to the bottom, particularly when the sediment includes organic matter, and the evil might be greatly diminished by more frequently cleaning out the cisterns. But it is to be particularly remarked, that this corrosion is not attended by any sensible solution of lead in the water, and that the water of the cistern is not poisoned in consequence. The London water may indeed be said to exert the least degree of solvent action upon lead.

Referring to the operations of liming water, so as to reduce its hardness, the authors remark :—

But it is the solvent action of soft water on lead which is calculated to excite most alarm, with the general use of house cisterns, and the universal use of service pipes of that metal, under the present system of distribution.

Of the soft spring waters from Surrey, the corrosive action on lead is remarkably small, according to our own observations, which generally accord with the conclusions of Mr. Napier on that point, with the striking exception of the water from the Punch Bowl, Hindhead, of which the power to dissolve lead proved to be rather considerable. The inactivity of the other samples we would refer more to the smallness of the quantity of dissolved oxygen which they contain, than to the absence of carbonic acid, the cause suggested by Mr. Napier.

River water or spring water from the chalk strata, softened artificially to about three degrees of hardness, was proved by our own observation, to have no dangerous action upon lead.

The experimental results obtained in a long inquiry, undertaken to illustrate the action of water in various circumstances upon lead, are not adapted for statement in this Report. The subject is one of great difficulty, and is still far from being exhausted. The most important practical conclusions which we have arrived at are the following :—

Certain salts, particularly sulphates, to which a protecting effect is usually ascribed, did not appear to exercise uniformly that useful property. Some salts, on the other hand, such as chlorides, and more particularly nitrates, may increase the solvent action of water. Of all protecting actions, that of carbonate of lime, dissolved in carbonic acid, appeared to be the most considerable and surest.

The most practical, perhaps, of our observations, is the extraordinary influence remarked of the small quantity of carbonic acid which water usually contains upon the results. This effect is fortunately to neutralize, to an extraordinary degree, the usual solvent action on lead which water exercises through the agency of the oxygen dissolved in it. The soluble oxide of lead is converted into the carbonate, which although not absolutely insoluble, appears to be the least soluble of all the salts of lead.

Carbonic acid is usually present in well, river and lake waters, in quantity sufficient for protection ; and the immunity of such waters from lead impregnation, we would ascribe often more to their carbonic acid than to the salts which they may also contain ; for lead placed in distilled water which has been boiled to expel its carbonic acid, is no longer sufficiently protected by the addition of the same salts.

Organic matter in a soft water, is doubly dangerous, as the rapid corrosion which it occasions may be followed by solution of the lead salt formed, when the carbonic acid is either deficient, as in rain water generally, or present above the safe proportion.

The properties of water which enable it to act at times with unusual vigour upon lead are little understood, and seem often to arise from the accidental action of local and very limited

causes, such as the presence of decaying leaves and impurities, which may only affect a small volume of water. These causes are of a kind most to be dreaded in the supply of a single residence, in which the whole volume of water might at a time assume the same dangerous composition. But such causes probably often counteract each other, when large volumes of water are mixed together, as in the supply for a town.

It is at least difficult to account otherwise for the fact, that no recent and authenticated case can be cited of the health of any of the numerous towns lately supplied with soft water being affected by the use of leaden distributory tubes, although apprehensions were often entertained from the introduction of soft water, as at Boston, in the United States, where the subject has excited much attention; and at New York since the introduction of the Croton River.

From Whitehaven, where water of extreme softness has been in use for the last six months, we learn that no case of lead poisoning has been seen or heard of by the medical practitioners of the town which could be attributed to the use of the water. No cisterns however are used there, nor in any other towns where soft water has lately been introduced, as they may be dispensed with on the system of constant supply, which appears always to have been adopted with the soft water.

We are disposed, therefore, to conclude that the danger from lead in town supplies of water has been over rated; and that with a supply from the Water Companies not less frequent than daily, no danger is to be apprehended from the use of the present distributory apparatus, with any supply of moderately soft water which the metropolis is likely to obtain.

Alfred Swaine Taylor, in a report on the water of the West Middlesex Water Co., records that the water supplied by the company (Thames water) has practically no action on lead. He states this is due to the saline matter, for "when the saline substances which it contains are separated from it by distillation, the water acquires a well marked impregnation with lead by a few minutes' contact with the metal." It is, therefore, evident that this

"Saline matter confers on it the property of resisting this chemical action on lead. We have further ascertained by diluting this water with variable proportions of absolutely pure or distilled water, that the action on lead became more and more apparent, until the water contained so little saline matter that the point of danger was reached. The innocuousness of this water supplied through lead, is inferred from direct experiment with the metal immersed in the water for long periods, under circumstances favourable to chemical action, as well as from the observation that no injurious effects have followed from the constant use of the cistern water (No. 7) during a period of seventeen years. The statements which have been published respecting the action of some kinds of *hard* waters on lead do not apply to the West Middlesex water, either in a chemical or medical point of view.

The water of the Bagshot sands is a soft water. Its great freedom from saline matter led to its becoming impregnated with lead, and caused the poisoning of the Queen's hounds, as well as an attack of painters' colic in one of the huntsmen. In another case, the same description of water led to the poisoning of thirteen out of thirty-eight persons in the establishment of the royal family of France at Claremont. Under the present mode of distribution and stowage, therefore, a water may be so pure as to endanger health and life by its action on lead. It is necessary that this fact should be fully impressed on the mind, or otherwise the excessive purity of the water may become an unsuspected source of injury to health. Although all *soft* water does not necessarily act upon lead, the above facts, as well as the analysis of Messrs. Brande and Warington, prove that the Bagshot water is beyond doubt exposed to the risk of noxious impregnation by contact with this metal.

Seven samples of the West Middlesex Company's water (Thames) were tested for lead, bars of the metal having been immersed in them for 19 days. Dr. Taylor reports that,

[In three] there appeared to be a very minute trace of lead in a soluble form, but according to a comparative estimate, the quantity thus dissolved could not have amounted to so much as the 1-280,000th part of the weight of the water. There are probably few waters which would not act on lead to this extent. We attribute this slight action on the metal to the accidental presence of some soluble nitrates. The proportion of lead present was wholly insufficient to render the water injurious in a dietetic point of view.

Dr. H. M. Noad, Professor of Chemistry at St. George's Hospital, in reporting on certain well waters in London, says :—

Water containing organic matter is particularly objectionable on account of its liability to become contaminated with *lead* when kept in cisterns of that metal, and that earthy and alkaline sulphates and chlorides, even when present in considerable quantity, do not in such waters act as preservatives.

Among the constituents of the well waters of large towns, *nitric acid* has often been alluded to. . . . That it does occasionally exist in large quantities, is shown by the analysis by Mr. W. Fisher, of a well water from Highgate. . . . Attention was directed to this water, *firstly*, in consequence of its powerful action on the leaden cistern in which it was retained, and *secondly*, on account of the unusual amount of saline matter which it contained. Its hardness has prevented its being much used for domestic purposes, which may probably be deemed a fortunate circumstance, as I have found the metal evidently acted upon after being immersed in a bottle of the water for a few days only. By the subjoined analysis, it will, I think, appear that the remarkable action of this water on lead is referable to the comparatively small quantities of sulphates and chlorides, and to the extraordinary amount of *nitrates* which it contains.

Speaking of a certain spring at Clapham, Dr. Noad reports its composition as follows, in grains per gallon :—

Silica	0·24
Carbonate of Lime	15·09
Carbonate of Magnesia	13·97
Sulphate of Lime	15·32
Sulphate of Potassa	6·79
Sulphate of Soda	10·77
Chloride of Sodium	11·46
Organic Matter	4·10
	77·74

Here, then, we have an instance of a water containing an abundance of so-called "preservative salts," corroding lead with remarkable energy.

To what are we to ascribe this remarkable action ? I believe to the presence in the water of an unusually large quantity of organic matter. It was during the summer months that the corrosion of the cistern took place so rapidly.

This is by no means the only instance I have met with of water abounding in sulphates and chlorides acting strongly on lead, and in every case that I have yet examined, organic matter has been present in unusual quantity. It is worthy of remark that no lead could be found in solution whenever this does occur, in any but pure or alkaline water ; the metal is probably taken up in the form of oxychloride ; carbonate of lead is wholly insoluble, even in water highly charged with carbonic acid. I mention this because an idea is very generally prevalent that carbonate of lead, like the carbonates of lime and magnesia, may be rendered soluble by taking up an extra atom of carbonic acid. I have made direct experiments, which negative this assumption.

But water, though it cannot take up carbonate of lead in solution, may, by keeping it in mechanical suspension, be the means of introducing this dangerous form of saturnine poison into the system. The practice of filtering water preserved in leaden cisterns, and intended for domestic use, cannot, therefore, be too warmly recommended.

Speaking of the artesian well waters of the London basin, he says :—

I wish, lastly, to say a few words on another class of waters which act strongly on lead. These waters are, I believe, always alkaline ; those which I have examined are remarkably free from organic matter, and as there is no deficiency of preservative salts, it is to their alkalinity that I am inclined to attribute the corrosive action which they exert on this metal.

Professor Crace Calvert, in a report on the water supply of the town of Preston, records five analyses ; and, respecting the action of the analysed waters on lead, he says :—

The action of the five waters on lead piping has received my attention. I cannot give a satisfactory explanation of the curious results I have obtained, as they are in contradiction to facts which I and other chemists have published ; for the two purest waters, Cowley Brook and north side of Longridge Hill, act with extreme slowness on lead. In fact, samples of these waters, after having been left two months in contact with perfectly cleansed lead piping, contained only a very small amount of lead ; whilst Dutton Brook, a water nearly as pure as the two above mentioned, contained a much larger amount. It is known that lead is rapidly attacked by pure waters, as rain or distilled waters, even when the latter has been boiled to expel any trace of air or carbonic acid it may contain. The action of the waters from Cowley Brook and Longridge Hill on lead piping cannot be ascribed to the presence of carbonic acid, as they only contain a usual proportion of that gas.

To settle this question, lead was put in contact with distilled water partly charged with carbonic acid ; but, although the lead was much less acted on than by another portion of the same water not containing this gas, still it contained more lead than samples of the waters from Cowley Brook and north side of Longridge Hill. Although the action of water on lead has drawn the attention of the most learned chemists, viz., Chevreul, Christison, Graham, &c., the subject is far from being exhausted. Dutton Brook service reservoir water, and Loudscales water have nearly the same action on lead ; but, although they act slowly, still they are much more active than the two first waters examined.

V.—Summary of Explanations generally adopted.

Having thus dealt in some detail with the literature of the subject, we shall endeavour to summarise the explanations that have been given by various observers to account for the different effects of water on lead.

Speaking generally, all observers record that whilst soft waters commonly act upon lead, hard waters do not. The majority assert even more than this, namely, that it is the nature of soft waters to act freely on lead.

No doubt the idea that soft waters must act on lead, had its origin in the fact that distilled water in contact with bright sheet lead, dissolves from six to eight grains per gallon.

The explanations to account for the non-action of certain waters on lead may be thus stated :—

(1.) *The presence in solution of mineral matter, and more especially of sulphates, carbonates, and phosphates.*

The first investigators held somewhat opposite views on this subject. Thus, Dr. Lambe insisted that natural waters acted on lead because they contained salts in solution, whilst Guyton Morveau thought that certain waters did not act on lead for the same reason. (See page 14.)

The first detailed experiments on this subject were made by Guyton Morveau in 1809 (*Annales de Chim.* lxxi. 197). They were principally directed to show the preservative action effected by lime sulphate. Thus he states that if the $\frac{1}{500}$th part of lime sulphate (or 140 grs. per gallon) be added to a distilled water, which acts freely on lead, the action will be effectually prevented. He further suggests, although there are no detailed experiments recorded,

that both nitrates and chlorides are endowed with a similarly preservative power.

Christison, about the year 1820, greatly extended the inquiries of Guyton Morveau. He records that whilst, without an exception, all neutral salts, but specially the phosphates, impair the solvent action of distilled water on lead different salts possess vastly different powers in this respect. The following are some of his results:

	Fractions of grain added per gallon.	Results.
Acetate of Soda	$\frac{1}{100}$	White crystals formed on lead. Lead dissolved, one-fourth of that taken up by distilled water.
Ditto	$\frac{1}{15000}$	Completely preservative.
Arseniate of Soda	$\frac{1}{20000}$	Not quite complete preservation.
Phosphate of Soda	$\frac{1}{30000}$	Completely preservative.
Ditto	$\frac{1}{35000}$	Not quite complete preservation.
Iodide of Potassium ...	$\frac{1}{30000}$	Completely preservative.
Chloride of Sodium ...	$\frac{1}{2000}$	Completely preservative.
Ditto	$\frac{1}{4000}$	Not quite complete preservation.
Sulphate of Lime	$\frac{1}{4000}$	Completely preservative.
Sulphate of Soda	$\frac{1}{4000}$	Completely preservative.
Ditto	$\frac{1}{6000}$	Not quite complete preservation.
Nitrate of Potash	$\frac{1}{100}$	Almost completely preservative.
Ditto	$\frac{1}{160}$	Loss about $\frac{1}{3}$ of the lead dissolved by distilled water.

In the experiments with solutions where the quantity of salt proved insufficient to effect perfect protection, [such as $\frac{1}{4000}$th of a grain of sodic chloride, the $\frac{1}{6000}$th of sodic sulphate, the $\frac{1}{15000}$th of sodic arseniate, and the $\frac{1}{35000}$th of sodic phosphate] he records the appearance of a coating on the lead of lead carbonate and of a lead salt of the acid contained in the salt, together with a deposit on the bottom and sides of the containing glass and a film on the surface of the water. But he notes that if the water under these circumstances be carefully filtered, no lead remains in solution.

On gradually decreasing the quantities of the protective salts, two results are noted :—(1) An increase in the quantity of the deposit, with an increasing ratio of the carbonate over the other lead salt ; and (2) a decreasing adhesion of the deposit formed upon the lead, a point being finally reached where a mere shake was sufficient to detach it.

Further Christison considers the preservative power to depend on the nature of the acid rather than on the base, for he records (1) that whilst sodic chloride, acetate, and phosphate differ in their protective powers, the sulphates of lime, magnesia, and soda are practically identical ; and (2) that the protective power of a salt depends on the insolubility of the compound which the lead forms with the acid of the salt. Thus acetate of soda, nitrate of potash, chloride of sodium, sulphate of lime, arseniate of soda, and phosphate of soda are protective, inversely as the acetate, nitrate, chloride, sulphate, arseniate, and phosphate of lead are soluble in water. He considers, however, that the protective action depends on something more than the formation of a lead compound with the acid. For example, if a piece of bright lead is placed in a solution containing a $\frac{1}{30000}$th part of phosphate of soda, no change in the lead

will be apparent for some days, after which a uniform white film of carbonate of lead (for Christison records it to be entirely soluble in acetic acid) will form on the metal. A few weeks later some phosphate of lead along with the carbonate will be deposited, a portion only now being soluble in acetic acid. This crust which forms very slowly, adheres to the lead with great tenacity. He further records a constant gain in the weight of the lead for some weeks; after which it remains stationary in weight, and ceases to be acted upon, even when immersed in pure distilled water.

Experiments on the preservative action of different salts are recorded by Dr. Nevins (*Pharmaceutical Journal*, 1850-51, p. 595). Some of his results are given in the following table :—

[The Lead was allowed to remain for one week in solutions of salts made with distilled water, except when otherwise noted.]

1. Sulphate of Magnesia ... 4 gr. to ℥j. 2. Ditto ... 10 gr. to ℥j.	Action same in both. Lead not protected. Bottom of jar and surface of lead became coated with a thick white layer, easily removed from the lead by scraping with the nail. Water turned black with H_2S.

3.   Ditto   ... ⎱ 4 grs. of each
    Bicarbonate of Soda ... ⎰   to ℥j.
4.   Ditto   ditto   ... ⎱ 10grs. of each
                  ⎰   to ℥j
5. Carbonate of Magnesia, partially dissolved by CO_2.
6. Carbonate of Lime, partially dissolved by CO_2.
	Lead not protected. Water became black when H_2S was passed through.
	The action in the case of 3 and 4 most marked. " It is evident that neither a large nor a small quantity of a sulphate acts as a protection in the presence of a soluble carbonate."

7. Sodic Chloride... ... 0·5 gr. to ℥j. 8. Ditto. ... ... 2·0 gr. to ℥j. 9. Ditto ... ... 0·5 gr. to ℥j. Of Liverpool water supply. 0. Ditto 0·2 gr. to ℥j. Ditto. 1. Mixtures of 0·5 gr. of NaCl with 1 gr. of sulphate of magnesia, and 2 gr. of NaCl with 4 gr. of sulphate of magnesia in ℥j. 12. Mixtures as above, chloride of calcium being substituted for chloride of sodium.	Lead less protected with the chloride of calcium than with the chloride of sodium. In the case of the sodic chloride no precipitate formed in the jar nor on the lead, but with the calcic chloride the lead was coated. The waters in all cases contained lead, but less than in experiments 1 to 6.

With respect to experiments 1 and 2, Dr. Nevins records that the small quantity of lime sulphate in the Liverpool water undoubtedly protects the lead. He explains that strong solutions of sulphate do not act like weak solutions, because when a precipitate is *rapidly* formed, it adheres to lead imperfectly. When the quantity of sulphate present is small, the deposit is formed *slowly*, its adhesion being then uniform and complete. He makes no distinction between the action of lime and magnesia sulphates on lead.

Dr. Nevins concludes by remarking that " it is clear that hard waters do not protect lead simply from the fact of their being hard."

The action of saline solutions on lead is the subject of a paper by M. Pattison Muir (*Proc. Manch. Lit. and Phil. Soc.*, xvi. 1-10 and 141-152, *Journal of Chemical Society*, xxxi., p. 660). He shows that :—

1. There is generally an increase in the solvent action of dilute saline solutions upon lead associated with increase of exposed surface of liquid, when the experiments are carried out in beakers loosely covered with porous paper.

2. When large surfaces of liquid are exposed, the increase of lead dissolved shows marked irregularity. The action of the air results in the formation

of an insoluble hydrocarbonate: in certain solutions this salt is more quickly formed than in others.

3. The solvent action of the saline solutions continues through lengthened periods of time. After several weeks it reaches a maximum.

4. Exposure of a given surface of lead to increasing volumes of the same liquid does not materially influence the quantity of lead passing into solution per unit volume of liquid.

5. The mechanical treatment of the lead materially alters its power of resisting the solvent action of dilute saline solution.

TABLE showing the lead dissolved in grains per imperial gallon of water, in which was dissolved the various salts in the quantities specified. [Water used 500 c.c. Lead exposed 5,600 sq. m. m.]

(M. M. P. Muir, *Chem. Soc. Journ.*, 1877.)

	Grains per gallon of salt added.	Grains of Lead dissolved per gallon after—		
		24 hours.	48 hours.	72 hours.
Ammonic Nitrate	1·4	0·91		1·75
Ditto	2·8	1·05		2·24
Potassic Nitrate	1·4	0·14	0·14	
Sodic Nitrate	3·5			
Potassic Nitrate	4·9			0·035
Potassic Sulphate	35·0			
Potassc Nitrate	3·15			0·021
Potassic Carbonate	2·156			
Calcic Chloride...	17·5	0·035	0·035	0·035
Ammonic Nitrate	1·4			
Calcic Chloride	4·2			0·126
Sodic Sulphate	1·4			
Potassic Carbonate	2·8			
Calcic Chloride	77·0			0·007
Potassic Carbonate	21·7			0·014
Distilled Water, with CO_2 at ordinary pressures		0·21		0·21
Distilled Water, with CO_2 at pressure of about six atmospheres ...		1·036	1·68	
Distilled Water		0·14	0·14	0·21

Solubility of Lead Hydrocarbonate 2 $PbCO_3$. $Pb(OH)_2$ in various saline solutions at ordinary temperatures (Muir).

	Grms. per litre in solution.	Lead Salts dissolved.	
		In corked flasks.	In beakers.
Ammonium Sulphate............................	·2	1 in 32,000	1 in 43.000
Potassium Nitrate	·2	1 in 26,000	1 in 43,000
Calcium Chloride.................................	·2	1 in 23,000	1 in 26,000
Ammonium Nitrate	·2	1 in 4,600	1 in 26,000
Water saturated with CO_2......................		1 in 4,300	1 in 4,300

Undoubtedly a water which derives its hardness from carbonate of magnesia is more likely to act on lead than one that derives its hardness from carbonate of lime. Again, magnesium chloride is a far more actively solvent agent than calcium chloride; whilst experiments appear to indicate that sodium chloride promotes solvent action more than either magnesium or calcium chlorides.

(2.) *The presence of an unusually large quantity of carbonic acid.*

" My friend Professor Daniel," says Dr. Pereira, "informs me that he has found lead in the well water obtained at Norwood. The water is *very hard* (that is, holds a large quantity of sulphate of lime in solution), and contains much free carbonic acid. It is the latter ingredient apparently that holds the lead in solution ; for by boiling the whole of the lead is precipitated. The water is raised from the well by a leaden pump, to which is attached a few feet of leaden pipe. Professor Daniell's attention was directed to the subject in consequence of the occurrence of several cases of lead colic in the neighbourhood of his residence at Norwood " (*Treatise on Food and Diet*, p. 96, 1843).

This view was opposed by Taylor, as well as by Graham, Miller, and Hofmann.

Our experiments lead us to the conclusion that carbonic acid prevents, rather than assists the action of water on lead. (See Muir's experiments, p. 32.)

Dr. George Wilson (*Lectures on Chemistry in the Edinburgh Medical School*) records the fact that Loch Katrine water, which acts very freely on lead, is

Remarkable for its freedom from carbonic acid, of which it contains so mere a trace that I have not attempted to determine its amount.

(3.) *The presence of an excess of oxygen (air) in solution.*

To the absence of dissolved oxygen, Graham, Miller, and Hofmann attributed the very slight action on lead of certain soft waters from Surrey.

Fourcroy refers to the non-action of water, free from air or oxygen, on lead (vol. vi., p. 111). He also records the activity of water containing air, especially when the lead is half immersed in the water, and mentions it as a subject that had been previously investigated by Luzuriaga.

Dr. George Wilson (Professor of Chemistry in the Edinburgh Extra-Academical Medical School), in reporting on Loch Katrine water, and after pointing out its freedom from carbonic acid, states :—

Of oxygen, on the other hand, it contains a large proportion. The amount of gas (nitrogen and oxygen) dissolved in the water is 6·83 cubic inches in the gallon. The amount of oxygen in the gallon is 2·28 cubic inches ; and the proportion of this gas present in any water is a *datum* of essential importance in estimating its action on the metals made use of in the pipes or tanks employed to convey or husband it.

It thus appears that Loch Katrine water proves on analysis to be a very soft, highly oxygenated water, and one, therefore, which it could not but be greatly feared would rapidly corrode lead. I will freely acknowledge, however, that I was not prepared for so rapid an action on lead as the water, in fact, exerts.

However full the pipes are of water, lead will be dissolved as a result of the action of the oxygen in the liquid (which the closed pipes do not permit to escape) on the metal, and the oxide thus produced will partly dissolve and partly remain suspended in the water.

Dr. Penny reports to the same effect.

(4.) *The presence of organic matter in solution.*

That the presence of organic matter in water is the direct cause of its action on lead, and that the extent of such action is in proportion to the amount of organic matter present, were views advocated by Dr. Noad. He records a case of a very hard water acting on lead, but he notes that it contained over 4·0 grains of organic matter per gallon. (See pages 19 and 28.)

Graham, Miller and Hofmann also record that organic matter occasions corrosion of lead, followed by solution of the lead salt formed. (See page 26.)

Horsford (Professor at the University of Cambridge, U. S. A.), holds an opposite opinion, namely, that the action on lead is lessened by the presence of organic matter. (See experiments with tannic acid, page 24.)

(5.) *The presence of an excess of nitrates, chlorides, &c.*

Dr. Noad considers that in many cases the action of water on lead depends on an excess of nitrates. He says :—

> Now, though the presence of earthy nitrates does not perhaps communicate any injurious or unwholesome quality to a water, indeed, from the entire absence of decomposing organic substances, it may be less objectionable as a beverage than the average waters of large cities, it is, nevertheless, important to bear in mind the powerful action of such waters on lead, and the possibility of its becoming the vehicle through which this subtle poison may be introduced into the system.

Graham, Miller and Hofmann consider chlorides (as well as nitrates) to increase the solvent action of water.

(6.) *The presence of acids arising from decaying organic (animal and vegetable) matter.*

That decaying leaves and similar organic matters favour the corrosion of lead by the development of various acids due to their gradual decomposition is a view favoured by Lindsay. (See page 18.)

(7.) *The presence of nitrite of ammonia.*

Medlock considers this to be the true cause generally of the action of water on lead. (*Record of Pharmacy and Therapeutics*, ii., 1857, p. 34.)

(8.) *The alkalinity of the water.*

This was urged by Noad as another explanation of the action of water on lead. (See page 19.)

In addition to these explanations, there are many accidental causes to account for certain unusually large quantities of lead occasionally found in solution. Such causes are the contact of pieces of mortar or lime with the lead (of which Pereira has recorded a case)—a lengthened exposure of water to a lead surface (*e. g.*, the water standing all night in the service pipes)—the use of leaden covers to cisterns and pipes, the pure water of evaporation acting readily on such surfaces and contaminating the water in the receiver—the use of combinations of metals where galvanic action assists solution (of which Christison records a case, the lead of a pipe being completely corroded on each side of a soldered joint, although the solder itself escaped corrosion) (*Pharm. Journ.*, 1844-45, p. 308), and other causes.

VI.—OCCURRENCE OF UNEXPLAINED DISCREPANCIES.

Notwithstanding all that has been done, we find chemist after chemist recording the unsatisfactory state of our knowledge as to the action of water on lead.

Graham, Miller, and Hofmann speak of the subject as one "*little understood,*" believing "that the danger from lead in town supplies of water has been over-rated."

Crace Calvert states, "I cannot give a satisfactory explanation of the curious results I have obtained, as they are in contradiction to facts which I and other chemists have published."

Similarly, the Consulting Physicians of Boston, also Sir R. Christison, Wilson of Edinburgh, and Dr. Penny speak of our knowledge on the subject as "unsatisfactory."

Our own experience, which, for the most part, is in accord with that of others, is to the following effect:—

I. That whilst hard waters, as a rule, do not act, exceptional cases occur where hard waters do act freely on lead.

Dr. Angus Smith records a case where a water containing 62 grains of lime salts per gallon dissolved lead freely. Noad has recorded similar cases (Report on Well Waters) of waters containing 13 and 77 grains per gallon, of which more than one-half were salts of lime and magnesia. Thomas Spencer even contended that "hard water in connection with lead was more dangerous than soft."

We are indebted to Mr. Pryor, of Old Broad Street, London, for a sample of spring water of 24 degrees of hardness, which dissolved lead with remarkable freedom. It had been, he informs us, conveyed through a lead pipe into certain kennels, and had caused lead poisoning among a pack of harriers.

It is worth recording that London water, of 13 degrees of hardness, has no action on lead. Even after boiling, whereby its hardness is reduced to 3 degrees, its non-action remains perfect.

II. That in the case of soft waters, two well-defined classes may be noted:—

(*a.*) Where the solvent action of the soft waters, which in the first instance act more or less on lead, diminishes day by day, until after a certain period, longer or shorter, the action ceases owing to the formation of a coating of some insoluble compound. It has been stated by some that this insoluble coating is a mixture of organic matter and oxide of lead (Horsford); by others, of carbonate of lead (Christison); and by others again of a suboxide of lead (Boston chemists).

Of such waters many cases may be noted. Thus, in many soft water towns visited by us, not a single sample of water drawn through the lead service pipes showed contamination with lead; although the water was extremely soft, and contained a very small quantity of solid matter in solution.

Reporting on water which was supplied to the Trossachs Hotel from a small mountain stream, and contained 2·5 grains of solid matter per gallon, and had a hardness of less than 1 degree, Dr. Penny writes, "This water acts very slightly on lead, and the action is not continuous." Dr. Penny, again, in a report on the Brockburn water, which contains 5 grains of solid matter per gallon and has a hardness of 3 degrees, says:—

I made a careful examination, in 1845, of the Brockburn water in regard to its action upon lead, and I have recently subjected it to additional investigations. The degree of action, even under the most favourable circumstances, is extremely slight. With common milled lead in open vessels it has never given, in any one of the many and varied experiments I have made, a sedimentary deposit, nor has the water ever become turbid or opalescent. The quantity of lead in solution, after prolonged contact, was found to be exceedingly small, and when the water was renewed, the presence of the metal was not afterwards appreciable. The metal soon became coated with a protecting film.

Dr. Penny refers, as further illustrations of the same fact, to the Tay water at Perth, to the Dee water at Aberdeen, to the Stanley Reservoir water at Paisley, and to the water supplied to Lanark. Thus, he concludes, " There are many soft and excellent waters that do not possess the objectionable property of acting continuously on lead."

(b.) Where the solvent action of those waters which act on lead does not diminish, but in some cases actually increases as time goes on. This was considered by Miller and Penny to be the case with Loch Katrine water; though their view seems scarcely to have been borne out by subsequent experience. Miller says :—

1st. The action of distilled and of Katrine water [on lead] goes on uninterruptedly, if the vessel be exposed to the air. I have specimens of the lake water which have been in contact with lead for nearly four months. The action is *now proceeding* as regularly as it did at first.

2nd. Whenever a piece of lead has been corroded, either by distilled water or by any other water, and this lead is transferred to Loch Katrine water, whether immediately or after allowing it to dry in the air, the corrosive action continues as rapidly as before.

3rd. Sheet or pipe lead which has been superficially coated by plunging it for a few days in hard water, or some water that does not corrode the metal, is not *corroded* when transferred to Katrine water ; but the *solvent* action of the Katrine water *is not prevented*, although retarded. I have invariably found lead in solution, in such Katrine water, after exposure for 24 hours, either to old sheet lead, or shut up in closed pipes. Sometimes, in the case of new pipes, I have had a crystalline deposit from the liquid on exposing it to the air, and this deposit has proved to be carbonate of lead.

VII.—RESULTS OF PERSONAL INSPECTION OF VARIOUS SOFT-WATER TOWNS.

Carefully considering the information we have now laid before you, we decided to commence our investigations by a personal inspection of various towns in different parts of England supplied with soft water, and by inquiries on the spot as to the effect of the water supplied to these various towns. In this report we have deemed it advisable, for obvious reasons, to refer to the several towns we visited by letter only.

We secured the co-operation in each town of the engineer in special charge of the water supply; and we desire here to express our obligations for the invariable readiness with which the necessary assistance was given and the information we required was afforded us.

In each case, we visited the source or sources from which the water supply of the town was derived, and collected samples of the water both before and after passing through the mains. The analyses of these waters were made on our return to London; but we carefully determined on the spot the reactions of the several waters at their respective sources, and in the reservoirs, and in the mains.

With the information afforded us, we selected a number of houses, representing as far as possible the entire area of supply, for the purpose of visiting and taking samples to examine for lead. In each case we recorded—

(1.) The diameter and length of the lead service pipe through which the water had to flow before it reached the house.

(2.) The length of time that each lead service pipe had been in use.

(3.) The size and condition (*i.e.*, whether coated or not) of the mains supplying the service pipes.

Further, in most cases two samples of water were taken at each house. The first sample was collected before any water was allowed to run to waste. This represented, more or less accurately, the condition of the water after standing, a longer or shorter time as the case might be, in the service pipe. The second sample was drawn after the water had been allowed to run to waste for two minutes or more. This represented the condition of the water after a rapid passage through, but without any prolonged contact with, the service pipe. These samples were duly labelled, and examined by us for lead on our return to the hotel at which we were staying.

In not a few of the samples so taken and at once examined, a proportion of lead was found varying from 0·05 to 1·50 grain of metallic lead per gallon of the water. The majority of the samples, however, afforded us only a negative result. By the often recurring statement that no lead, or no trace of lead was present, we mean to imply that the quantity was less than the $\frac{1}{100}$th of a grain per gallon, whilst probably we might affirm with certainty that the quantity of lead, if any, in solution was less than the $\frac{1}{150}$th of a grain per gallon.

Further, in certain of the towns visited, we obtained samples of old lead pipes that had been taken up and replaced; and we afterwards submitted the deposits found in these pipes to examination.

A.

We were given to understand that no complaints of lead poisoning had been heard of for several years past in this town. The supply is taken from a river, the water of which is conveyed by a brick aqueduct to a large reservoir, from which sundry other reservoirs are fed. We were informed that certain ochrey springs found their way into the large supply reservoir, but we were not ourselves able to discover any evidence of such springs.

The reaction of the water was tested by us at numerous spots in the river, in the aqueduct, in the reservoir, and in the mains, and found to be neutral. No departure from this neutrality was observable even after some hours' contact of the water with litmus paper.

Three samples of the water were collected for analysis, viz. :—

(1.) From the river.

(2.) From the reservoir.

(3.) From a 15-inch main in the town.

The following are the results of the analyses (See note, page 1) :—

	1.	2.	3.
Free Oxygen (c.i. per gall.) ...	2·10	1·93	2·07
Total Solids	2·60	2·55	3·35
Ammonia	0·00	0·00	0·00
Nitrogen = Nitric Acid	0·00	0·00	0·00
Oxygen required to oxidise, &c.	0·172	0·190	0·163
Organic Carbon (per 100,000)...	0·342	0·351	0·346
Organic Nitrogen (per 100,000)	0·031	0·034	0·027
Silica	0·36	0·35	0·40
Lime	0·504	0·448	0·840
Magnesia	0·144	0·108	0·108
Chlorine = Common Salt	0·427 = ·705	0·427 = ·705	0·427 = ·705
Hardness—			
Before boiling	2·3°	1 8°	3·2°
After boiling.....................	1·6°	1·6°	1·6°

The action of the water on lead was carefully examined by placing bright sheet lead in open vessels in contact with the water :—

After 1 hour	...	...	Lead dissolved	= 0·03 gr. per gallon.
After 3 hours	...	...	„	= 0·061 gr.	„
After 24 hours	...	...	„	= 0·47 gr.	„
After 2 days	...	...	„	= 1·28 gr.	„

After two days the further solvent action of the water was practically *nil*.

A new lead pipe, 6 feet long and 1·5 inches diameter, was filled with the water. After two days, lead to the extent of 0·54 grain per gallon was found in the water. The water was examined at the end of the month, and the quantity of lead present found to be practically identical with that recognisable after two days' contact. The water was perfectly clear when drawn from the lead pipe.

Thirty-six samples of the water as supplied, were examined for lead. The service pipes through which these samples were delivered had been in use for periods varying from 6 months to 35 years, three being more than 30 years, and seven between 20 and 30 years old. The lengths of the service pipes varied from 5 to 50 yards, more than 50 per cent. being over 25 yards long.

All the samples collected had a neutral reaction, and no trace of lead was found in any one of them.

The lead pipes showed little deposit, even after they had been in use for many years. The corrosion of the non-coated iron mains, we may record in passing, was very excessive. At the same time, it is noteworthy that no iron was found by us in any of the samples of water. The engineer informed us that the lead pipes after being down for many years became brittle.

Partial analyses of the deposits in the pipes gave the following percentage results :—

	1.	2.	3.
Carbonic Acid	1·421	1·310	1·84
Loss on incineration..............	8·41	5 36	6·28
Insoluble in Nitric Acid	7·14	6·30	7·00
Silica	2 61	2·18	5·14

B.

The water supplied to this town was duly examined by us at the reservoir, and there found to be neutral.

Five samples were taken for analysis, three (1, 2, and 3) from the reservoirs before entering the mains, and two (4 and 5) from the principal mains in the city.

The following are the results of the analyses :—

	1.	2.	3.	4.	5.
Free Oxygen	1·87	2·29	1·96	2·01	2·01
Total solids	7·60	3·15	3·15	3·25	2·85
Ammonia	0·00	0·00	0·00	0·00	0·00
Nitrogen = Nitric Acid	0·00	0·00	0·00	0·00	0·00
Oxygen required to oxidise, &c.	0·086	0·103	0·103	0·122	0·127
Organic Carbon	0·210	0·224	0·246	0·252	0·251
Organic Nitrogen ..	0·020	0·022	0·031	0·021	0·023
Silica...............	0·41	0·40	0·46	0·36	0·51
Lime	1·90	0·672	0·728	0·503	0·672
Magnesia	0·540	0·180	0·216	0·144	0·252
Chlorine = Common Salt	1·0 = 1·65	0·5 = ·82	0·5 = ·82	0·5 = ·82	0·427 = ·705
Hardness—					
Before boiling	5·1°	2·0°	1·9°	3·5°	4·6°
After boiling	3·3	2·0°	1·6°	2·0°	2·6°

The action of these waters on bright sheet lead was tested, with the following results :—

After 1 hour	...	...	Lead dissolved = 0·04 gr. per gallon.
After 24 hours	...	...	„ = 1·17 „ „
After 2 days	...	...	„ = 1·185 „ „

No increase of lead beyond this was found after an interval of ten days, during the whole of which time the water had remained in contact with the metal.

A new lead pipe, 6 feet long by 1·5 inches diameter, was filled with the water. This, after two days, contained 0·81 grains of lead per gallon, but the quantity of lead in solution had not appreciably increased after retention of the water in the pipe for one month.

Twenty-nine samples of the water, as supplied to houses in the town, were examined for lead. The service-pipes through which these samples were delivered had been in use for periods varying from 6 months to 30 years. The lengths varied between 50 and 120 feet. Not a trace of lead was found in any one of the samples.

The lead pipes showed little deposit. One analysis, made of the deposit, yielded as follows :—

Carbonic Acid	...	...	...	...	...	...	...	2·21
Loss on Incineration	...	...	...	...	...	...	15·10
Insoluble in Nitric Acid...	...	...	...	...	...	7·1
Silica	...	...	...	...	...	...	...	4·1

C.

The water in all the reservoirs supplying this town was found to be neutral.

Six samples were taken for analysis. The first five were from reservoirs, and the sixth from the principal main in the town.

The results obtained are as follows:—

	1.	2.	3.	4.	5.	6.
Free Oxygen	2·01	2·09	1·96	1·96	2·32	1·93
Total Solids	7·35	6·40	4·0	5·15	12·4	7·75
Ammonia	0·00	0·00	0·00	0·00	0·00	0·00
Nitrogen = Nitric Acid	0·00	0·00	0·00	0·00	·328 = 1·475	0·00
Oxygen required to oxidise organic matter	0·095	0·129	0·148	0·125	0·009	0·090
Organic Carbon.........	0·200	0·264	0·281	0·237	0·071	0·184
Organic Nitrogen	0·016	0·015	0·025	0·021	0·023	0·024
Silica	0·50	0·41	0·25	0·31	0·41	0·44
Lime	2·07	1·95	1·00	1·73	3·69	2·75
Magnesia..................	0·504	0·468	0·396	0·360	0·792	0·575
Chlorine = Common Salt	0·696 = 1·150	0·636 = 1·052	0·636 = 1·052	0·636 = 1·052	1·061 = 1·750	0·696 = 1·052
Hardness—						
Before boiling	7·0°	5·1°	2·6°	3·7°	7·0°	6·0°
After boiling	2·8°	2·4°	2·4°	2·8°	3·3°	1·8°

The action of these six waters on bright sheet lead was tested, with the following results:—

Lead dissolved. Per gallon.	1.	2.	3.	4.	5.	6.
After 1 hour	0·04	0·04	0·05	0·04	0·03	0·02
After 24 hours	1·06	1·054	1·28	1·17	1·04	1·05
After 2 days	1·17	1·17	1·41	1·30	1·15	1·15
After 10 days............	1·17	1·27	2·17	2·61	1·15	1·16

A sample of the water taken from one of the mains of the city, and having a hardness before boiling of 7·5 deg., and after boiling of 2·0 deg., was placed in a new lead pipe, 9 feet long and 1·0 inch in diameter, so as to fill it, and allowed to remain in the pipe for twenty-four hours. The lead dissolved was equal to 0·826 grain per gallon.

Thirty-six samples of water supplied to the town were examined with the following results:—

(1.) In one sample we found 0·15 grain of lead per gallon. The water had been standing in a perfectly new pipe in a not yet occupied house. The water, after running for two minutes, contained 0·05 grain of lead per gallon.

(2.) In a second sample, also from a new house, a trace of lead was found, both in the water first drawn and in that collected after a flow for two minutes.

(3.) A minute trace of lead was found in water that had been standing for some time in a pipe two years old and 80 feet in length.

(4.) No lead was detected in any of the other thirty-three samples. The age of the pipes varied from being perfectly new to 50 years and more, and the length from 12 to 120 feet.

D.

All the samples examined were found to be neutral.

Two samples were collected for analysis, (1) from the reservoir, (2) from the mains in the city.

The results obtained are as follows :—

	1.	2.
Free Oxygen	2·04	2·07
Total Solids	1·65	1·70
Ammonia	0·00	0·00
Nitrogen = Nitric Acid	0·00	0·00
Oxygen required to oxidize organic matter	0·145	0·136
Organic Carbon	0·251	0·248
Organic Nitrogen	0·028	0·021
Silica	0·30	0·30
Lime	0·280	0·372
Magnesia	0·408	0·108
Chlorine = Common Salt	0·5 = 0·825	0·5 = 0·825
Hardness :—		
Before boiling	1·0°	0·8°
After boiling	1·0°	0·8°

The action of this water on lead was duly tested and found to be energetic. Thus acting on bright sheet lead in the open, the results were as follows :—

After 15 minutes ... ... Lead dissolved = 0·1 gr. per gallon.
„ 1 hour ... ... „ = 0·9 „ „
„ 3 „ ... ... „ = 1·8 „ „ *
„ 24 „ ... ... „ = 3·4 „ „ *
„ 7 days ... ... „ = 4·5 „ „ *
„ 21 „ ... ... „ = 5·1 „ „ *

A new lead pipe, 6 feet long, by 1·5 inches diameter, being filled with the water, the following results were obtained :—

After 1 hour ... ... Lead dissolved 0·235 gr. per gallon.
„ 3 „ ... ... „ 0·46 „ „
„ 10 „ ... ... „ 0·80 „ „
„ 10 days ... ... „ 1·75 „ „

Forty-two samples of the water as supplied were examined for lead. The service pipes through which these samples were delivered had been in use for periods ranging from a fortnight to 40 years. The length of the service pipes varied from 20 to 80 feet.

(1.) In five cases a trace of lead was recorded, the water being drawn from pipes 36, 35, 50, 30 and 45 feet in length respectively, and of ages from 5 months to 15 years.

(2.) In one case the water yielded 0·07 grain of lead per gallon when first drawn, and "a minute trace" only after two minutes' run. The pipe was 46 feet long, and had been down for 3 weeks.

(3.) In one case the water gave 0·15 grains of lead per gallon, when first drawn, but none after two minutes' run. The pipe was practically a new pipe, 36 feet long.

The remaining thirty-five samples contained no lead.

The deposits from certain old pipes were examined and yielded as follows :—

	1.	2.
Carbonic Acid	0·41	1·31
Loss on incineration	16·21	14·10
Silica	1·24	1·62

* In these cases the water became opalescent, and there was a manifest sediment. The amount of lead given includes this sedimentary matter.

F

E.

The water of this town was of a dark peaty tint. Every sample examined was recorded as slightly acid.

Two samples were taken for analysis, (1) from the high level main, (2) from the low level main. The results obtained are as follows :—

	1.	2.
Free Oxygen	2·10	2·07
Total Solids	4·20	3·81
Ammonia	0·00	0·00
Nitrogen=Nitric Acid	0·00	0·00
Oxygen required to oxidise organic matter	0·345	0·287
Organic Carbon	0·516	0·483
Organic Nitrogen	0·040	0·041
Silica	0·80	0·70
Lime	0·728	0·392
Magnesia	0·288	0·216
Chlorine=Common Salt	0 696=1·150	0·696=1·150
Hardness—		
Before boiling	1·8°	1·8°
After boiling	1·6°	1·2°

The action of the water on lead was duly tested by placing pieces of bright sheet lead in contact with the water, with the following results :—

After 1 hour   ...   ... Lead dissolved = 0·01 gr. per gallon.
" 24 "   ...   ...   "   = 0·64 "   "
" 3 days ...   ...   "   = 1·14 "   "
" 10 "   ..   ...   "   = 1·15 "   "

A new lead pipe, 6 ft. × 1·5 in., was filled with the water. After two days, the water contained 0·06 grain of lead per gallon; but there was not any sensible increase beyond this after thirty-two days.

Twenty-eight samples of the water were drawn from service pipes which had been in use for periods varying from a few days to 15 years. The length of the pipes varied from 20 to 80 feet. No lead was found in any of the samples.

None of the deposits in the lead pipes were examined.

F.

The whole of the samples examined in this town were found to be neutral.

The analysis of two samples of water, collected (1) from the reservoirs, and (2) from the principal mains, gave the following results :—

	1.	2.
Free Oxygen	2·01	2·13
Total Solids	2·31	2·40
Ammonia	0·00	0·00
Nitrogen=Nitric Acid	0·00	0·00
Oxygen required to oxidise organic matter	0·007	0·018
Organic Carbon	—	0·040
Organic Nitrogen	—	0·020
Silica	0·65	0·70
Lime	—	0·100
Magnesia	—	0·080
Chlorine=Common Salt	0·50=0·825	0·50=0·825
Hardness—		
Before boiling	0·8°	1·2°
After boiling	0·8°	0·8°

The action of the water on bright sheet lead was noted to be as follows:—

After 1 hour	ead dissolved 0 01 gr. per gallon.
„ 24 „	„ 0·62 „ „
„ 3 days	„ 0·84 „ „
„ 20 „	„ 0·84 „ „

Twenty-eight samples of the water supplied were examined for lead. The pipes varied in length from 10 to 60 feet, and in age from a few days to 20 years. No trace of lead was found in any of the samples.

The deposit from one pipe was examined. It yielded:—

Carbonic Acid	1·10
Loss on incineration	2·10
Iron as Fe_2O_3	8·40

G.

No case of lead poisoning from the water, we were informed, had reached the authorities of this town. All the samples examined by us were found to be neutral.

Samples were taken for analysis, and gave the following results, (1) from the main, and (2) from the reservoir:—

	1.	2.
Free Oxygen	2·208	2·235
Total Solids	2·61	2·51
Ammonia	0·001	0·001
Nitrogen=Nitric Acid	0·00	0·00
Oxygen required to oxidise organic matter	0·023	0·028
Organic Carbon	0·121	0·068
Organic Nitrogen	0·020	0·020
Silica	0·39	0·41
Lime	0·806	0·862
Magnesia	0·518	0·554
Sulphuric Acid (SO_3)	0·219	0·219
Chlorine=Common Salt	0·86=1·42	0·72=1·18
Hardness—		
Before boiling	0·8°	0·8°
After boiling	0·4°	0·4°

The action of the water on lead was duly examined.

A new lead pipe, 6 ft. × 1·5 in., filled with the water, dissolved 0·68 grain of lead in twenty-four hours, and 1·15 grains in two days. Examined after twenty days, the lead found was equal to 1·28 grains.

Twenty-eight samples of the water, as drawn from the service pipes, were examined. The pipes varied in length from 10 to 100 feet, and in age from 2 days to 20 years.

A minute trace of lead was found in three samples. The remaining twenty-five samples were perfectly free from lead.

H.

All the samples examined were found to be neutral.

The analysis of a sample of water taken from the mains gave the following results:—

Free Oxygen	2·31
Total Solids	3·68
Ammonia	0·002
Nitrogen = Nitric Acid	0·146 = 0·657
Oxygen required, &c. ...	0·042
Organic Carbon.............	0·116
Organic Nitrogen	0·030
Silica	0·50

Lime	0·436
Magnesia	0·281
Sulphuric Acid (SO₃) ...	0·361
Chlorine=Common Salt	1·08 = 1·77
Hardness :—	
Before boiling	1·2°
After boiling............	0·8°

The action of the water on bright sheet lead was duly tested, with the following results :—

After 1 hour	Lead dissolved = 0·06 gr. per gallon.
„ 24 „	„ = 0·84 „ „
„ 2 days	„ = 1·15 „ „
„ 4 „	„ = 1·20 „ „
„ 10 „	„ = 1·21 „ „
„ 21 „	„ = 1·21 „ „

Seventeen samples of water drawn through service pipes, varying in length from 8 to 100 feet, and in age from one week to 20 years, were examined.

(1.) In one case, that of a pipe 50 feet long, and about twenty years old, through which the water had not been drawn for five days, the first drawn water contained 0·3 grain of lead per gallon, but no lead was found in the water after a two minutes' run.

(2.) In a second case, that of a pipe 25 feet long, and five years old, in which the water had been standing for four days, a minute trace of lead was found in the water first drawn, but none in that collected after a two minutes' run.

The remaining fifteen samples were entirely free from lead.

The deposit in the pipes yielded :—

Carbonic Acid	4·0
Loss on incineration	5·6
Silica	3·74

I.

We were informed that no cases of lead poisoning from use of the water had of late been heard of by the authorities.

All the samples examined by us from the supply pipes were neutral.

Seven samples, all taken from the service-reservoirs, were submitted to examination with the following results :—

	1.	2.	3.	4.	5.	6.	7
Free Oxygen	2·146	1·822	1·822	1·960	1·876	1·876	1·739
Total Solids	4·12	7·20	4·74	4·93	6·46	6·16	4·78
Ammonia	0·002	0·001	0·002	0·002	0·001	0·001	0·002
Nitrogen = Nitric Acid..............	0·00	0·00	0·00	0·00	0·00	0·00	0·00
Oxygen required to oxidise, &c........	0·062	0·043	0·062	0·024	0·98	0·121	0·027
Silica	0·28	0·12	0·30	0·22	0·25	0·32	0·26
Lime	0·644	1·019	0·476	0·503	0·649	0·649	0·840
Magnesia	0·309	0·562	0·417	0·450	0·504	0·497	0·324
Sulphuric Anhydride	1·60	1·51	1·52	1·63	—	1·50	—
Chlorine = Common Salt	0·648 = 1·062	0·720 = 1·180	0·792 = 1·298	0·648 = 1·062	0·720 = 1·180	0·648 = 1·062	0·720 = 1·180
Hardness— Before boiling .... After boiling......	2·0	3·3	2·4	2·4	2·4	2·0	1·6°

The action of the water on bright sheet lead was duly tested, with the following results :—

After 1 hour ...	...	...	...	Lead dissolved	= 0·03 gr. per gallon.
„ 24 „ ...	...	...	...	„	= 0·78 „ „
„ 2 days ...	...	...	...	„	= 1·15 „ „
„ 4 „ ...	...	...	...	„	= 1·91 „ „
„ 7 „ ...	...	...	...	„	= 2·53 „ „
„ 21 „ ...	...	...	...	„	= 2·96 „ „

Placed in a new lead pipe, 6 ft. × 1·5 in., the action of the water on the lead was equally continuous :—

After 1 day ...	...	...	...	Lead dissolved	= 0·41 gr. per gallon.
„ 2 „ ...	...	...	...	„	= 0·85 „ „
„ 3 „ ...	...	...	...	„	= 0·91 „ „
„ 7 „ ...	...	...	...	„	= 1·24 „ „
„ 14 „ ...	...	...	...	„	= 1·58 „ „
„ 21 „ ...	...	...	...	„	= 2·07 „ „
„ 28 „ ...	...	...	...	„	= 2·23 „ „

Forty-two samples of water drawn through service pipes varying in length from 25 to 480 feet, and in age from one week to 25 years, were examined, with the following results :—

(1.) In one case, the water contained 0·2 gr. of lead per gallon—length of pipe 60 feet, age six months.

(2.) In two cases, 0·15 gr. of lead per gallon was found—(1) length of pipe 40 feet, age nine months; (2) length 70 feet, age one month.

(3.) In two cases, 0·1 gr. of lead per gallon was found—(1) length of pipe 50 feet, age four months ; (2) 480 feet, age twenty years.

(4.) In one case, 0·07 gr. of lead per gallon was found—length of pipe 50 feet, age three months.

(5.) In four cases, 0·05 gr. of lead per gallon was found :—

(1) Length of pipe, 54 feet	...	...	...	age 6 years.
(2) Length of pipe, 150 feet	...	...	...	age 9 months.
(3) Length of pipe, 60 feet	...	...	...	age 4 years.
(4) Length of pipe, 70 feet	...	...	...	age 1 week.

(6.) In one case, 0·02 gr. of lead per gallon was found—length of pipe 35 feet, age three years.

(7.) In eleven cases the lead present was recorded as " a trace."

In the remaining twenty cases no lead was found in the water.

A sample of the deposit in one of the lead pipes gave the following results :—

Carbonic Acid ...	...	...	...	...	1·78
Sulphuric Acid (SO_3) ...	...	...	...	17·10
Lead Oxide (PbO)	...	...	...	...	69·20
Silica ...	...	...	...	...	...	1·81

K.

The water as drawn from the supply pipes was neutral.

We were unable to obtain any definite information as to how far lead poisoning due to the water supply of the town had been complained of. It was admitted, however, that some cases of lead poisoning from this cause had come to the knowledge of the authorities.

Analysis was made of three samples, 1 and 2 from the mains, 3 from the reservoir, as follows :—

	1.	2.	3.
Free Oxygen........................	1·97	1·88	1·987
Total Solids	4·30	10·40	9·10
Ammonia	0·001	0·002	0·001
Nitrogen=Nitric Acid............	0·052=0·234	0·052=0·234	0·052=0·234
Oxygen required to oxidise,&c.	0 055	0·067	0·052
Organic Carbon....................	0·151	0·172	0·160
Organic Nitrogen..................	0·030	0·030	0·034
Silica	0·19	0·28	0·29
Lime	1·23	3·08	2·09
Magnesia	0·612	0·970	0·896
Sulphuric Acid	1·60	2·61	1·70
Chlorine=Common Salt.........	0·648=1·062	0·720=1·180	0·720=1·180
Hardness—			
Before boiling	4·2	6·5	4·3
After boiling....................	2·4	4·5	3·3

The action of the water on bright sheet lead was duly examined with the following results :—

After 1 hour	...	...	...	...	Lead dissolved	0·5	gr. per gallon.	
„ 1 day	...	...	...	...	„	1·14	„ „	
„ 2 „	...	...	...	...	„	1·28	„ „	
„ 3 „	...	...	...	...	„	1·65	„ „	◦
„ 4 „	...	...	...	...	„	2·14	„ „	◦
„ 5 „	...	...	...	...	„	2·51	„ „	◦
„ 7 „	...	...	...	...	„	2·83	„ „	◦
„ 14 „	...	...	...	...	„	3 57	„ „	◦
„ 21 „	...	...	..	...	„	4·90	„ „	◦
„ 28 „	...	...	...	...	„	8·21	„ „	◦
„ 35 „	...	...	...	...	„	14·00	„ „	◦

Twenty-one samples of water drawn through service pipes varying in length from 25 to 120 feet, and in age from six months to 30 years, were examined, with the following results :—

(1.) In two cases, 0·4 gr. of lead per gallon was found—(1) length of pipe, 80 feet, age one year ; (2) length 50 feet, age seven years.

(2.) In one case, 0·35 gr. of lead was found—length 25 feet, age eight years.

(3.) In one case, 0·17 gr. of lead was found—length 120 feet, age five years.

(4.) In three cases, 0·15 gr. of lead was found—(I) length 60 feet, age eight years ; (2) length 120 feet, age one year—(3) length 60 feet, age five years.

(5.) In three cases, 0·1 gr. of lead was found—(1) length 100 feet, age six years ; (2) length 30 feet, age twenty years ; (3) length 40 feet, age five years.

(6.) In two cases, 0·07 gr. of lead was found—(1) length 40 feet, age four years ; (2) length 40 feet, age twelve years.

(7.) In three cases, 0·05 gr. of lead was found—(1) length 60 feet, age two years ; (2) length 40 feet, age twelve years ; (3) length 30 feet, age three years.

(8.) In one case, 0·03 gr. of lead was found—length 60 feet, age six months.

(9.) In three cases, the water was noted as containing a trace of lead

◦ All these samples were turbid.

—(1) length 100 feet, age six months; (2) length 50 feet, age four years; (3) length 120 feet, age ten years.

(10.) In two samples only was no lead found—(1) length 40 feet, age thirty years; (2) length 40 feet, age five years.

Some deposit in one of the old lead pipes was examined. It yielded:—

Carbonic Acid	5·1
Loss on incineration	8·3
Silica	1·01

L.

The analysis of three samples of the water, No. 1 being taken from the mains and Nos. 2 and 3 from the reservoirs, gave the following results. The reaction of all three samples was faintly acid :—

	1.	2.	3.
Free Oxygen	1·91	2·04	2·04
Total Solids	5·5	5·1	6·7
Ammonia	0·001	0·001	0·001
Nitrogen=Nitric Acid	0·052=0·234	0·000	0·000
Oxygen required to oxidise, &c.	0·034	0·035	0·039
Organic Carbon	0·141	0·138	0·110
Organic Nitrogen	0·031	0·036	0·030
Silica	0·14	0·26	0·20
Lime	1·39	1·176	1·231
Magnesia	0·432	0·216	0·720
Sulphuric Anhydride	1·68	0·80	1·38
Chlorine=Common Salt	0·720=1·180	0·648=1·062	0·720=1·180
Hardness—			
Before boiling	2·7°	2·0°	2·4°
After boiling	2·4°	2·0°	2·4°

The action of the water on bright sheet lead was noted to be as follows :—

After 1 hour ...	...	...	...	Lead dissolved	0·04 gr. per gallon.
,, 12 ,, ...	...	...	...	,,	0·60 ,,	,,
,, 24 ,, ...	...	...	...	,,	0·71 ,,	,,
,, 2 days ...	...	...	...	,,	1·31 ,,	,,
,, 6 ,, ...	...	...	...	,,	2·54 ,,	,,	o
,, 18 ,, ...	...	...	...	,,	4·28 ,,	,,	o
,, 21 ,, ...	...	...	...	,,	5·30 ,,	,,	o
,, 28 ,, ...	...	...	...	,,	8·61 ,,	,,	o
,, 40 ,, ...	...	...	...	,,	10·8 ,,	,,	o
,, 2 months ...	...	...	,,	14·1 ,,	,,	o

Twenty-one samples of water drawn through service pipes varying in length from 15 to 150 feet, and in age from fourteen days to 20 years, were examined with the following results :—

(1.) In one case, 1·5 gr. of lead per gallon was found—length of pipe 60 feet, age one month. [Note.—No water had been drawn from the pipe for twenty-four hours.]

(2.) In three cases, 0·6 gr. of lead per gallon was found—(1) length 36 feet, age three months; (2) length 120 feet, age five weeks; (3) length 31 feet, age three weeks.

(3.) In one case, 0·5 gr. of lead was found—length 15 feet, age fourteen days.

° These samples were turbid.

(4.) In one case, 0.4 gr. of lead was found—length 36 feet, age six years.

(5.) In three cases, 0.3 gr. of lead was found—(1) length 36 feet, age three months; (2) length 13 feet, age six months; (3) length 27 feet, age twelve years.

(6.) In one case, 0.2 gr. of lead was found—length 90 feet, age six years.

(7.) In two cases, 0.1 gr. of lead was found—(1) length 45 feet, age three years; (2) length 24 feet, age four years.

(8.) In one case, 0.07 gr. of lead was found—length 60 feet, age two months.

(9.) In two cases, 0.05 gr. of lead was found—(1) length 150 feet, age twenty years; (2) length 24 feet, age ten years.

(10.) In three cases, the presence of "a trace of lead" was recorded.

(11.) In three cases, only was the water found entirely free from lead.

M.

All the samples collected showed a neutral reaction. We were given to understand that no complaints had reached the authorities of lead poisoning from the water supply.

We found no iron springs at the reservoirs.

The analysis of three samples, No. 1, from the mains in the town, and Nos. 2 and 3 from the reservoirs, gave the following results:—

	1.	2.	3.
Free Oxygen	1·84	—	1·31
Total Solids	6·4	4·02	4·96
Ammonia	0·002	0·002	0·001
Nitrogen=Nitric Acid	0·052=0·234	0·000	0·000
Oxygen required to oxidise, &c.	0·058	0·036	0·083
Organic Carbon	0·161	0·128	0·210
Organic Nitrogen	0·030	0·021	0·030
Silica	0·19	0·21	0·20
Lime	1·39	0·39	0·42
Magnesia	0·360	0·288	0·439
Sulphuric Acid (SO_3)	—	1·04	0·21
Chlorine=Common Salt	0·648=1·062	0·720=1·18	0·720=1·18
Hardness—			
Before boiling	3·2°	1·6°	1·6°
After boiling	2·0°	1·6°	1·6°

The action of this water on bright sheet lead was noted to be as follows:—

A new lead pipe, 9 feet long, and 1.5 inches diameter, was filled with the water, and the contents examined at the intervals stated:—

After 12 hours	...	...	...	...	Lead dissolved	0·31 gr. per gallon.
„ 1 day	...	...	...	...	„	0·40 „ „
„ 2 „	...	...	...	...	„	0·71 „ „
„ 3 „	...	...	...	...	„	0·80 „ „
„ 7 „	...	...	...	...	„	1·27 „ „
„ 14 „	...	...	...	...	„	1·26 „ „
„ 21 „	...	...	...	...	„	1·84 „ „
„ 28 „	...	...	...	...	„	2·51 „ „

Twenty-six samples of water drawn through service pipes varying in length from 15 to 450 feet, and in age from a few weeks to 40 years, were examined by us.

(1.) In one case, 0·4 grs. of lead per gallon was found—length of pipe 400 feet, age three months.

(2.) In one case, 0·3 gr. of lead was found—length 100 feet, age eight months.

(3.) In two cases, 0·2 gr. of lead was found— (1) length 100 feet, age eighteen months ; (2) length 15 feet, age two months.

(4.) In four cases, 0·15 gr. of lead was found—(1) length 100 feet, age one year ; (2) length 80 feet, age four months ; (3) length 150 feet, age twelve years ; (4) length 60 feet, age forty years.

(5.) In four cases, 0·1 gr. of lead was found—(1) length 80 feet, age ten years ; (2) length 18 feet, age three years ; (3) length 120 feet, age five years ; (4) length 100 feet, age forty years.

(6.) In three cases, 0·07 gr., 0·05 gr. and 0·025 gr. of lead were found respectively.

(7.) In eight cases, the presence of a trace of lead was recorded.

(8.) In three cases, no lead was found.

N.

The analysis of (1) a sample of water from the pure water tank, and (2) from one of the chief iron mains of this town, gave the following results. The reaction of both samples was neutral.

	1.	2.
Free Oxygen	2·208	2 070
Total Solids	2·70	2·32
Ammonia	0 000	0·000
Nitrogen=Nitric Acid	0 000	0·000
Oxygen required to oxidize organic matter	0·038	0·069
Organic Carbon	0·128	0·139
Organic Nitrogen	0·030	0·036
Silica	0·47	0·42
Lime	0·532	0 448
Magnesium	0·324	0 288
Sulphuric Acid (SO_3)	0·107	0·131
Chlorine=Common Salt	0·79=1·30	0·79=1·30
Hardness—		
Before boiling	1·2°	1·2°
After boiling	0·8°	0·8°

The action of the water on a new lead pipe, 9 feet long, 1·5 inches diameter, was noted to be as follows :—

After 12 hours	...	...	...	...	Lead dissolved	0·05 gr. per gallon.
,, 1 day	...	...	...	...	,,	0·29 ,, ,,
,, 2 ,,	...	...	...	...	,,	0·54 ,, ,,
,, 3 ,,	...	...	...	...	,,	0·66 ,, ,,
,, 4 ,,	...	...	...	...	,,	0·66 ,, ,,
,, 7 ,,	...	...	...	...	,,	0·68 ,, ,,

Thirty-two samples of water drawn through service pipes varying in length from 10 to 125 feet, and in age from 1 week to 25 years, were duly examined.

In the case of two pipes that had been laid less than 14 days, we recorded

G

a trace of lead in the first drawn water. No trace of lead was found in the remaining thirty samples.

O.

At this town there had been serious imputations of lead-poisoning having resulted from the use of the water supplied. Numerous samples drawn from the services were found to contain lead to a notable extent, but the exact quantities in solution in the water were not estimated.

The analysis of samples of the water supply from this town gave the results as follows. The reaction was in all cases neutral. No. 2 was drawn from the mains. The other five samples were from reservoirs.

	1.	2.	3.	4.	5.	6.
Free Oxygen	—	—	—	—	—	—
Total Solids	4·9	5·2	4·0	3·7	4·2	4·8
Ammonia	0·005	0·003	0·001	0·002	0·005	0·001
Nitrogen = Nitric Acid	Trace.	Trace.	0·035 = 0·157	0·035 = 0·157	0·035 = 0·157	0·035 = 0·157
Oxygen required to oxidise organic matter	0·61	0·71	0·54	0·58	0·58	0·60
Silica	0·10	0·14	0·32	0·18	0·20	0·11
Chlorine = Common Salt	0·576 = 0·944	0·576 = 0·944	0·648 = 1·062	0·648 = 1·062	0·648 = 1·062	0·648 = 1·062
Hardness—						
Before boiling ...	1·2	1·2	1·0	1·0	1·0	1·0
After boiling... ...	1·2	1·2	0·8	0·8	0·8	0·8

The action of two of the waters upon lead was carefully noted.

Tested with pieces of sheet lead exposed to the air, the following results were obtained :—

After 1 hour ... ... Lead dissolved 0·31 gr. per gallon.
„ 12 „ ... ... „ 1·78 „ „
„ 24 „ ... ... „ 3·56 „ „ *
„ 3 days ... ... „ 5·10 „ „ *
„ 5 „ ... ... „ 6·80 „ „ *
„ 8 „ ... ... „ 9·11 „ „ *
„ 20 ... ... „ 15·21 „ „ *
„ 30 „ ... ... „ 18·16 „ „ *
„ 40 „ ... ... „ 20·00 „ „ *

The waters were placed in new lead pipes, 9 feet long, and 0·5 inch diameter, and allowed to remain for 24 hours.

Pipe No. 1 ... ... Lead dissolved 2·617 gr. per gallon.
Pipe No. 2 ... ... „ „ 3·210 „ „

The experiment was repeated with fresh water in the same pipes, the result being :

Pipe No. 1 ... ... 2·51 | Pipe No. 2 ... ... 3·10

* These samples were all turbid.

P.

The action of two of the supplies of this town on lead were noted. Supply No. 1 had an initial hardness of 2·4 degrees, which on boiling was reduced to 1·6 degrees. It contained one grain of common salt per gallon. Supply No. 2 had an initial hardness of 12·1 degrees, which, after boiling, was reduced to 2·0 degrees.

Both waters were placed in new lead pipes, 6 ft. × 1·5 in., and allowed to remain in contact with the lead for 24 hours.

No. 1   ...   .   Lead dissolved 1·529 gr. per gallon.
No. 2   ...   .   „   „   None.

VIII.—ACTIVE AND INACTIVE SOFT-WATER SUPPLIES.

The above-stated results show that the soft water supplies which had come under our observation might be classed primarily as follows:—

Class I.—Supplies where the water delivered through lead service pipes contained lead in appreciable quantity. Of this class, I, K, L, M, and O are illustrations.

Class II.—Supplies where the water delivered through lead service pipes contained no recognizable quantity of lead. Of this class, A, B, E, F, and N are illustrations.

Class III.—But in addition to these two well-characterized classes, there appeared to be a third and intermediate class of supplies, where lead was indeed detectable in the water after passage through the service pipes, although the quantity was insignificant. Of this intermediate class C, D G, and H are illustrations.

The important question thus presented itself for our consideration, as to whether there was any discoverable difference in the composition, or in the other behaviour, of these three different classes of soft water, which were observed to act on the lead service pipes in these three different ways. That certain differences in composition and behaviour are irrelative to the particular difference under discussion, is obvious from an inspection of the following Table, in which some of the more important results of the above detailed individual examinations are set forth:—

	Lead in Water from Service Pipes.	Hardness of Water in Mains.	Solvent Action of Water on Clean Sheet Lead after			Solvent Action of Water on New Lead. Pipe after	
			24 Hours.	48 Hours.	72 Hours	24 Hours.	48 Hours
A. —	None.	3·2°	0·47	1·28	...	...	0·54
B. —	None.	3·5°–4·6°	1·17	1·18	...	...	0·81
C.	Traces.	6·0°	1·28	1·30	...	0·82	...
D.	Traces.	0·8°	3·40	...	...	0·46*	...
E. —	None.	1·8°	0·64	...	1·14	...	0·06
F. —	None.	1·2°	0·62	...	0·84	...	...
G.	Traces.	0·8°	...	...	...	0·68	1·15
H	Traces.	1·2°	0 84	1·15	...	...	...
I. +	·05 to ·20	2·0°?	0 78	1·15	...	0·45	0·85
K. +	·05 to ·40	4·3°?	1·14	1·28	1·65	...	...
L. +	·05 to 1·50	2·7°	0·71	1·31	...	...	...
M. +	·05 to ·40	3·2°	...	...	...	0·40	0·71
N. —	None.	1·2°	...	...	...	0·29	0·54
O. +	Considerable.	1·2°	3·56	...	5·10	3·2	...

It appears, for instance, from the Table, that the liability of soft water to act permanently on lead, is irrelative to the variation in its degree of softness, or irrelative, that is, to its low degree of hardness. Thus, while several supplies of 1·2 degree of hardness were without action on the lead services, other supplies, of as much as 3·2 and 4·3 degrees of hardness, were among those of which the action was most considerable. Per contra, a particular supply, B, of 3·5 to 4·6 degrees of hardness, was without action, while another supply, O, of but 1·2 degrees of hardness, acted to a very marked extent. Again, the capability of soft water to act permanently on the lead services, is not necessarily relative to the extent of its activity on clean and new lead. Thus the supply, B, which on exposure to clean sheet lead for 24 hours, was found to take up 1·17 grain per gallon of lead, was quite without action on the lead services; whereas other supplies, I and L, which after the same length of exposure to clean sheet lead, were found to have taken up only 0·78 and 0·71 grain per gallon of lead, were among the examples acting most strongly on the lead services.

One curious fact, which had not up to this time been suspected by us, was clearly shown by the analyses, namely, the relatively large proportion of silica in those waters (viz., A, B, E, F, and N) where no lead was found in the supplies, as compared with its amount in those waters (viz., I, K, L, M, and O) in which lead was found. Thus in the former series (A, B, E, F, and N) the silica in the water averaged 0·53 grain per gallon, whilst in the latter (I, K, L, M, and O) it only averaged 0·21 grain, or constituted about two-fifths of that present in the former case. Moreover, in no single instance was a water with more than 0·5 grain per gallon of silica found

* After three hours only.

to exert a solvent action on the services; and in no instance was a water with less than 0·3 grain per gallon of silica found to be without such solvent action. This was the first link in the chain of evidence showing the dissolved silica to have some important influence in preventing the continuous action of water on lead.

A second link was afforded by the circumstance that not only was no lead found in those samples of the water containing above a certain quantity of silica, when supplied through lead pipes, but that in laboratory experiments the solvent action of these waters on lead ceased after a short time, three days being about the extreme limit. On the other hand, where the silica was present in the water in small quantity, the action on the lead seemed to be continuous, the amount of lead dissolved depending on the length of time that contact between the water and metal was permitted.

A third link in the chain was afforded by the analysis of the deposits in the lead pipes themselves. Whilst the average quantity of silica in the pipe-deposits, where no lead was found in the waters delivered, was 3·8 per cent., the silica in the deposits where lead was found in the waters only amounted to 1·4 per cent. And, curiously enough, this quantity, 1·4 per cent., was about two-fifths that of the quantity, 3·8 per cent., where no lead was found, thus giving additional strength to the first link we have called attention to.

A fourth link was afforded by the detailed analyses of the intermediate class of waters. Here the average silica in solution in the water was 0·39 grain per gallon, intermediate between ·21 and ·53 grain; whilst the silica in the pipe deposits furnished by these waters was 2·58 per cent., intermediate between 1·4 and 3·8 per cent.

We have placed these average results in the following statement, which may perhaps more clearly illustrate the special points to which we desire to direct attention.

I. Supplies where the water delivered through service pipes contained notable quantities of lead. (I, K, L, M, O.)

Silica found in water (average). Grain per gallon.	Silica found in deposit of pipe (average). Per cent.
0·21	1·4

These five supplies were found, in laboratory experiments, to act continuously on lead after 28 (2), 35, 40, and 60 days, the action not materially lessening by the lapse of time.

II. Supplies where the water delivered through service pipes contained practically no lead. (A, B, E, F, N.)

Silica found in water (average). Grain per gallon.	Silica found in deposits (average). Per cent.
0·53	3·8

These five supplies were found to act on lead from 2 to 3 days, after which the action ceased.

III. Supplies where traces of lead were found in a few of the samples

delivered through service pipes, although, for the most part, in insignificant quantities only. (C, D, G, H.)

Silica found in water (average). Grain per gallon.	Silica found in deposits (average). Per cent.
0·39	2·58

These four supplies were found to act on lead after 2, 4, 10, and 21 days, although not to the same extent as those included in Class I.

It was these results which led us to think that the true explanation of the circumstance why certain soft waters act on lead for a short period only, was to be found in the larger proportion of dissolved silica present in these waters, and the consequent formation of an insoluble lead silicate as a coating in the pipe.

IX.—LABORATORY EXPERIMENTS TO DETERMINE THE CAUSE OF THE INACTIVITY.

We deemed it advisable in the first instance to make a series of careful laboratory experiments, an outline of which we record.

The lead pipes employed were half an inch in internal diameter and 3 feet long. Their contents were 28 cubic inches, or 459 cubic centimetres. They were supported in a sloping position in a cool part of the laboratory. The lower part was closed by a cork through which passed a short glass tube, furnished with an india-rubber tube and a pinch-cock.

Temperature was found to have a great effect on the action of silicated waters on lead,—an anomalous result, which was many times observed, being ultimately traced to the fact that one of the pipes stood in a rather warmer part of the laboratory than the other pipes.

The mode of testing was as follows :—The lead pipe was filled with the water to be tested, and the whole allowed to stand at rest for twenty-four hours ; at the end of that time 50 cubic centimetres were drawn off and tested for lead by faintly acidulating with acetic acid and adding sulphuretted hydrogen. The amount of lead was estimated quantitatively by a colour test; or, when the quantity present was very small, it was expressed by the words " traces," " faint traces," or " doubtful."

After drawing off the 50 cubic centimetres for examination, an equal amount of the water under test was poured into the upper part of the lead pipe, so as always to keep it full.

The colorimetric observations were made in the following manner. Twenty clear glass bottles were respectively filled with solutions of lead acetate of the following strengths :—

No.	1	contained	0·01	grain of lead per gallon.	
,,	2	,,	0·02	,,	
,,	3	,,	0·03	,,	,,
,,	4	,,	0·04	,,	,,
,,	5	,,	0·05	,,	,,
,,	6	,,	0·06	,,	,,
,,	7	,,	0·07	,,	,
,,	8	,,	0·08	,,	,,
,,	9	,,	0·09	,,	,,
,,	10	,,	0·10	,,	,,
,,	11	,,	0·11	,,	,,
,,	12	,,	0·12	,,	,,
,,	13	,,	0·13	,,	,,
,,	14	,,	0·14	,,	,,
,,	15	,,	0·15	,,	,,
,,	16	,,	0·16	,,	,,
,,	17	,,	0·17	,,	,,
,,	18	,,	0·18	,,	,,
,,	19	,,	0·19	,,	,,
,,	20	,,	0·20	,,	,,

To each of these bottles sulphuretted hydrogen was added. These solutions being well corked up, formed a series of tinted liquids, from which, when freshly made, the approximate amount of lead in any of the experimental waters could be readily estimated by comparison. The water under examination was always tested in a similar bottle to those containing the standard liquids.

At first the silica was added in the form of sodium silicate; a quantity of silicate, equal to $\frac{6}{10}$ths of a grain of silica per gallon, being added to the water. The solution was faintly alkaline. It was, however, soon found that an excess of alkali had an injurious effect, causing a silicated water to act more or less on lead, when it would not otherwise have done so.

A. The first series of experiments, after the preliminary tentative ones, was performed with a solution of silica prepared by dialysis. A dilute solution of sodium silicate was exactly neutralised with hydrochloric acid and set to dialyse. After the soluble salt was removed, the solution was found to contain 0·0326 gramme of silica in 100 cubic centimetres.

This solution was mixed with distilled water in such a proportion that it contained $\frac{6}{10}$ths of a grain of soluble silica per gallon. A clean lead pipe was then filled with the solution, and it was allowed to remain at rest for twenty-four hours. The water was then tested, the pipe was refilled up, and another twenty-four hours allowed to elapse. Daily tests of the water were made in this way for seventeen days, but, after the second day, no trace of lead was found in it.

The lead pipe used in the last experiment, having had a daily charge of silicated water in it for seventeen days, was filled up with distilled water and allowed to stand at rest for three days, a small sample being drawn off each twenty-four hours for testing; in no case was lead detected in the water. This result appears to show that lead which has acquired an efficient coating of silicate is proof against the corrosive action of distilled water for, at all events, several days.

The same pipe was then carefully cut down the middle longitudinally, and the inner coating scraped off with a knife. On analysis it was found to contain silica, equal to 0·000064 grm. per square inch of surface.

B. A sample of soda-glass containing no lead was finely ground and digested in cold distilled water, with frequent shaking, for a week. The supernatant liquid, which was alkaline to litmus paper, was then filtered, and its action on lead was tested in the manner described above. The experiment was in this case continued for forty days, the water being tested every day. Decided traces of lead were found for the first few days; the amount gradually got less until it was sometimes doubtful whether or not lead was present. Up to the last day of the test, however, we could not feel certain that lead was wholly absent.

C. Some English lead glass was powdered and tested in the above manner, the aqueous solution being allowed to act on the lead pipe for seventeen days; the results were very similar to those with the soda-glass, as lead was found in the water, off and on, nearly the whole time, although in very minute traces; sometimes the amount being recorded as doubtful, and sometimes as altogether absent. The water filtered from the powdered glass was faintly alkaline.

D. Powdered granite was now tried. As the coarse powdering in this case had been done in an iron mortar, the particles of iron were separated by means of a magnet. The mineral was then finely powdered, and digested for a week in pure water with constant shaking. The experiment was continued for twenty-six days, the water being tested every morning. For the first few days not a trace of lead could be seen; then a faint colouration was occasionally noticeable, and afterwards the indications were either very faint or doubtful.

It has already been observed that excess of alkali somewhat interferes with the preservative action of silica; and the failure of granite to completely protect lead may, accordingly, be due to the comparatively large quantity of alkali which it contains. The water in which the granite had been digested was alkaline to test paper.

Finely powdered granite was boiled for several hours in dilute hydrochloric acid, then well washed in water, till every trace of acidity was removed, and finally set to digest in cold distilled water for several days, with frequent shaking. The action of the clear, filtered liquid on lead was then tested in the manner already described. At first a trace of lead was detected, this soon became less, and finally disappeared. The experiment lasted twenty-four days and, with the exception of the first five days, no lead was detected in the water at any time. 1000 cubic centimetres of this clear "granite water," evaporated to dryness with hydrochloric acid, gave 0·0164 gramme of silica, equivalent to 1·148 grains per gallon.

E. The next experiment tried was with ground flint. The flints selected were of large size, and only the inside black part was taken for the experiments. The fine powder was shaken up with distilled water for some days, and then filtered. The clear filtrate was tested for its action on lead in the usual

manner. The water was examined daily for forty-three days; for the first few days lead was found in the water, but in gradually diminishing quantities. It then disappeared, and for the last thirty-eight days the water was found to be free from lead. Some of this "flint water" was examined for silica, and found to contain 0·75 grain per gallon.

It was noted that after the ground flints had been repeatedly extracted with water, the water shaken up with the residue commenced to act a little on the lead pipe. Probably the small quantity of alkali present in flint was washed out by the earlier extractions, and not enough alkali left at last to cause sufficient silica to enter into solution.

A mixture of ground flint and pure precipitated calcium carbonate was now digested in cold water, and experimented with in the usual way. At first no lead was detected, then a trace was found, then none, then a faint trace, afterwards a doubtful trace, and so on for the twenty-seven days the experiment lasted. The preservative action was very marked, but it was not so complete as in other instances.

F. Agate was the form of silica next taken. The finely-powdered mineral was extracted with water, and the solution tested in lead pipe in the usual manner. The trials lasted fourteen days, and during the whole of that time lead, either as "traces" or "doubtful," could be detected in the water. 500 cubic centimetres of the "agate water" gave, on analysis, 0·0028 gramme of silica, equivalent to 0·392 grains per gallon.

The agate powder was now boiled for some time in dilute hydrochloric acid, and after its thorough washing, the experiments as above described were repeated. There was little, if any, improvement in the protective action, there being always a trace of lead in the water during the fourteen days the experiment lasted. On analysis, the aqueous solution was found to yield 0·0078 gramme of silica in 1000 cubic centimetres, equal to 0·546 grains per gallon.

G. Chalcedony was the next siliceous mineral operated on. The fine powder was well shaken up with water for some days, and the filtered liquid tested in a lead pipe. At first the presence of lead was decided, it then diminished, and finally it was doubtful. The protective action of this mineral was less than that of many others experimented on. The water filtered from the chalcedony left on evaporation 0·0976 gramme of total residue from 1000 cubic centimetres. This was strongly alkaline to test paper, and effervesced with acids; it gave 0·0286 gramme of silica in 1000 cubic centimetres, or 2·002 grain per gallon.

The general result of the foregoing experiments is, therefore, to show that, provided excess of alkali is absent, an amount of silica in solution equal to 0·6 of a grain per gallon is sufficient to deprive distilled water of any continuous solvent action on lead. Even in the least successful of these experiments the effect of silication in *reducing* the action of the water on the lead was most remarkable.

In what degree, if in any, the character of hard water in general to

H

be without appreciable action even on fresh lead may be related to the proportion of silica present in the hard water, is a subject foreign to our particular inquiry; though it may, perhaps, be worthy of remark that silica is a well-recognised constituent of most varieties of more or less hard water; the mean proportion in Thames water, for instance, as calculated from numerous published analyses, being over 0·6 grain per gallon. Our investigation, however, has reference only to soft water; the special point we have endeavoured to solve being the difference in the composition of different varieties of soft water on which their different action on lead services is dependent. In other words, we have endeavoured to find out why it is that while all varieties of soft water act more or less freely on new lead, this action, in the majority of cases, ceases after a little while, whereas in other cases it continues permanently. On this point it would seem to result from our experiments and observations that while the proportion of silica present in soft water does not appear to have any striking effect in reducing the action of the soft water on new lead, or causing it to approximate in this respect to hard water, it does seem to have a very notable effect in arresting the continued action of the soft water on lead some time in use.

X.—Continuation of Laboratory Experiments on a Larger Scale.

The above considerations suggested the advisability of a series of experiments on a larger scale. Three lengths of new lead pipe, 9 feet long by 1·5 inch in diameter, were filled with distilled water. This was permitted to remain in the pipes for twenty-four hours. The same three pipes were then used for five consecutive twenty-four-hour experiments with distilled water, to which proportions of dialysed silica varying from 0·1 to 0·5 gr. per gallon were added, the water employed each day containing 0·1 gr. of additional silica over that of the preceding day. The following results were obtained :—

			Lead dissolved per gallon.		
			1.	2.	3.
			Grains.	Grains.	Grains.
1st day.	Distilled Water		1·30	1·28	1·36
2nd day.	,,	+ 0·1 gr. Silica	1·41	1·48	1·52
3rd day.	,,	+ 0·2 gr. ,,	0·96	0·82	1·10
4th day.	,,	+ 0·3 gr. ,,	0·20	0·14	0·70
5th day.	,,	+ 0·4 gr. ,,	0·02	0·02	0·07
6th day.	,,	+ 0·5 gr. ,,	0·0	0·0	0·0

An inverse experiment was now made with the same three pipes. The point having been reached at which the water was lead-proof, the silica in the water was reduced 0·1 gr. day by day. The results obtained were as follows :—

	Lead dissolved per gallon.		
	1.	2.	3.
	Grains.	Grains.	Grains.
7. Distilled water with 0·4 gr. Silica	0·0	0·0	0·0
8. ,, with 0·3 gr. ,, ...	0·0	0·0	0·02
9. ,, with 0·2 gr. ,, ...	0·04	0·06	0·10
10. ,, with 0·1 gr. ,, ...	0·71	0·94	1·41
11. ,, with 0·0 gr. ,, ...	0·90	1·30	1·57

These results indicated that although the presence of a certain quantity of silica in a water prevented more or less its action upon lead, it was essential in order to ensure permanent protection that the quantity of silica in the water should be maintained. It is possible, indeed, supposing the quantity of silica in the water to be sufficiently large, and the contact of such water with the lead to be for a sufficient number of days, that a preservative coating of some thickness might be formed which should be able to protect the lead for a considerable time. (See bottom of page 55.)

Our next experiments were made with Blackmoorfoot water put into new lead pipes of the same size and length as those employed in the last experiments described. In this case it will be noted that the Blackmoorfoot water became lead proof when the added silica amounted to 0·4 gr. per gallon. This Blackmoorfoot water contains normally about 0·2 gr. per gallon. The results obtained were as follows:—

	Lead dissolved per gallon.		
	1.	2.	3.
	Grains.	Grains.	Grains.
Blackmoorfoot Water..	0·68	0·91	0·84
,, + 0·1 gr. Silica	0·37	0·51	0·40
,, + 0·2 gr. ,, ...	0·06	0·10	0·08
,, + 0·3 gr. ,, ...	0·02	0·03	0·03
,, + 0·4 gr. ,, ...	0·0	0·0	0·0

We now filled the same pipes, used in the last experiments, with ordinary Blackmoorfoot water. The water that was stood in the pipes for the first twenty-four hours dissolved respectively 0·3, 0·3 and 0·35 gr. of lead per gallon, whilst the lead dissolved by the water during the next twenty-four hours was 0·81, 0·78, and 0·61 grs. per gallon, a quantity equal to, or even exceeding, that dissolved by the same water in the first instance before any silicated water had been passed through the pipe.

From these experiments we seem to have grounds for concluding—

1. That a water becomes lead-proof when the dissolved silica is about 0·5 gr. per gallon.

2. That it is essential, in order to ensure this protective action, that the silication of the water should be maintained; as otherwise the deposit

formed may be dissolved, and the activity of the water on the lead again manifest itself.

A series of experiments was now made to determine how best to silicate the water without materially affecting its natural hardness. We decided, after much consideration and many experiments, to use a mixture of broken flints and limestone. It was found that the permanent lead-dissolving power of the water was more steadily kept under by contact with a mixture of the two minerals than with either separately, whilst the actual increase of hardness induced did not exceed one degree. The following details, each result being the average of six experiments, will indicate our meaning. Each water was allowed to remain in the lead pipe for 24 hours, and the dissolved lead then estimated.

	Grains of lead dissolved per gallon.
Water (natural)	1·016
„ after 1 hour's contact with limestone	0·460
„ „ „ „ flints and limestone	0·012

Mr. Jarmain has been good enough to carry out certain experiments at our request, the details of which are set forth below. They give nearly similar results. They were conducted with Blackmoorfoot water, a ½-inch lead pipe 64 yards long being employed.

Natural Water.	Lead per gallon. Grains.	Lead per gallon. Grains.
(1.) After remaining in lead pipe for periods varying from 1 to 3 days (11 experiments)	0·482	
(2.) After merely being run through the lead pipe (5 experiments)		0·19
Water after 5 minutes' contact with Buxton limestone.		
(1.) After remaining in lead pipe for periods varying from 20 to 72 hours (12 experiments)	0·272	
(2.) After merely being run through lead pipe (12 experiments)		0·06
Water after 5 minutes' contact with Buxton limestone mixed with half its bulk of broken flints.		
(1.) After remaining in lead pipe for periods varying from 24 to 72 hours (19 experiments)	0·16	
(2.) After merely being run through lead pipe * (19 experiments)		0·01

It may be interesting here to refer to the suggestion made by Anderson and Dugald Campbell, to bring the Loch Katrine water to Glasgow through a conduit of old red sandstone whereby, as they stated, though they did not profess to explain the *modus operandi*, the water would be deprived of its power of dissolving lead. They declared that by this means the hardness would be increased by not more than 1 degree, and the total solid matter by about 0·5 grain per gallon. Dundas Thompson reported to a similar effect. (See pages 22 and 23.)

George Wilson, who appeared for the petitioners against the bill, admitted the action of the sandstone on the water when left standing in contact with it

* In 12 experiments no lead at all was found dissolved.

for some hours, or when well shaken with it, but doubted how far beneficial action would result by merely passing a stream of water through an aqueduct of the material. Further, he considered that when the soluble matters out of the sandstone had been exhausted, its virtue would be at an end. He further said :—

Were it intended to filter the water *through* fragments of red sandstone frequently renewed, then the results obtained in experiments on the small scale would supply a trustworthy basis for speculations regarding the use of such a filter ; but they justify no conclusion as to the ameliorating influence of the mere surface of the stones of the proposed conduit.

And again—

That the saturation of Loch Katrine water with carbonate of lime would increase its hardness and render it indifferent to lead, is certain ; but the mere passage of the water over pieces of limestone would be a most imperfect way of securing this end.

We have little doubt that the explanation of the action of the red sandstone, which was not understood at the time, is to be found in the silica which it afforded to the water under the conditions made use of.

XI.—Testing of Proposed Remedy at the Deerhill Reservoir.

From a consideration of the result of these experiments it was decided to fill the gauge basin of Deerhill reservoir with mixed limestone and flints, and to allow the water to flow over the mixture. We were fully aware that the method at best was a rough one ; but we considered that its trial might indicate how far our experiments on a small scale would be likely to answer upon a comparatively large one.

Examinations of the water were made before and after its passage over the mixed flint and limestone. In each case a lead pipe, 9 ft. long by 1·5 in. in diameter, was completely filled with the water and allowed to stand for 24 hours, the lead taken up by the water then being estimated. Our average results, each the mean of thirty experiments, were as follows :—

	Lead per gallon.
Deerhill water before passing over limestone and flints	= 1·926
,, after ,, ,, ,, ...	= 0·35

Mr. Jarmain also made a series of experiments with the water, and his average results are as follows. They were made in a ½ inch lead pipe, 20 yards long.

	Lead per gallon.
Deerhill water before passing over flint and limestone	= 1·36 grs.
,, after ,, ,, ,, ...	= 0·37 gr.

It was found that the water, after its passage over the limestone and flint, had on some occasions a maximum increased hardness of about one degree, whilst at other times it was less than half a degree. We give here two detailed

analyses of the water before and after treatment. It is to be noted that in both cases the water was acid; and further that the total solids were increased by 0·8 gr. per gallon, the silica by 0·15 gr. per gallon, and the hardness by $\frac{4}{10}$ths of a degree.

	Before Treatment.	After Treatment.
Free Oxygen	1·79	1·73
Total Solids	2·8	3·6
Ammonia	0·001	0·001
Nitrogen = Nitric Acid	0·052 = 0·234	0·052 = 0·234
Organic Nitrogen	0·007	0·010
Silica	0·21	0·36
Lime	0·316	0·524
Magnesia	0·252	0·360
Chlorine = Common Salt	0·720 = 1·18	0·720 = 1·18
Hardness—		
Before boiling	2·0°	2·4°
After boiling	1·4°	1·8°

Many other samples of the Deerhill water, before and after it had passed over the limestone and flints, were examined. Speaking generally, experiments showed that comparing the water from the reservoir, before it had passed over the flint and limestone, with the water from the mains, after it had passed over the flint and limestone, the lead-dissolving power of the latter was greatly diminished, whilst its hardness was but very slightly added to.

The experiments on Deerhill water, of which the results are stated below, differ only from those already described in that the samples of this water, subjected to the action of the flint and limestone, were drawn from the mains, instead of being taken from the overflow of the gauge-basin. Each of the two results is the average of twenty-five experiments, in each of which the water was allowed to stand for 24 hours in similar lead pipes, 9 ft. in length and 1·5 in. in diameter.

	Lead per gallon.
Deerhill water from reservoir before treatment	2·314 grs.
„ „ from mains after „	0·095 „

We were particularly struck, on examining the flints in the gauge-basin two or three weeks after they had been put down, at the remarkable disappearance of their knife-like edges. Indeed the sharp edges had been entirely replaced by rounded and worn ones. That the water had exerted a strong solvent action upon the flints, the naked-eye inspection of the residue incontestably proved.

We are indebted to Mr. Jarmain for a series of further observations of daily samples of the filtered Deerhill water between February 12 and March 17, 1883, which practically confirm the results we have already set forth :—

Tests of Samples of Deerhill Water put into a 20-yards length of half-inch lead pipe. The words "before" and "after" imply before and after contact with limestone and flint in the gauge basin.

Date.	Time in pipe.	Before.		After.		Remarks.
		Hardness.	Lead per gallon.	Hardness.	Lead per gallon.	
1883.	Hours		Grs.			
Feb. 12	48	1·5°	1·4	2·9°	None	
13	24	1·9°	1·4	4·0°	None	
14	28	1·5°	1·28	4·4°	None	
15	20	1·4°	1·5	1·9°	·5 gr.	Water stagnant in gauge basin all night.
16	24	1·4°	1·4	2·6°	None	Ditto, but flowing slightly previous day.
17	24	1·5°	1·2	2·3°	None	Good stream flowing through previous day and night.
19	48	1·5°	1·4	1·9°	·9	Stagnant from Saturday morning.
20	24	1·5°	1·4	2·5°	None	Flowing previous day; stagnant during night.
21	28	1·5°	1·4	2·8°	None	Good stream running previous day and night.
22	20	1·5°	1·4	1·9°	·88	Stagnant previous night.
23	24	1·6°	1·6	3·2°	·06	Good stream through previous day and night.
24	24	1·6°	1·6	1·9°	·7	Stagnant previous night.
26	48	1·6°	1·4	2·9°	·1	
27	24	1·6°	1·4	2·8°	·05	
28	48	1·6°	1·4	2·0°	·45	
March 1	24	1·6°	1·4	2·5°	·12	
2	20	1·6°	1·4	2·2°	·12	
3	24	1·6°	1·3	2·0°	·17	
5	48	1·6°	1·5	1·7°	1·2	
6	24	1·6°	1·4	2·0°	0·48	Running through gauge 2″ deep, 86 gallons per minute.
7	24	1·6°	1·38	1·8°	0·74	Running through gauge ¼″ deep.
8	24	1·7°	1·38	2·2°	0·1	Running through gauge 2″ deep, 86 gallons per minute.
9	24	1·6°	1·38	2·3°	0·9	
10	24	1·9°	1·36	2·3°	0·54	Water stagnant on lime and flints for 12 hours.
12	48	1·9°	1·48	2·3°	0·64	Water stagnant on lime and flints for 36 hours.
13	24	1·8°	1·4	2·0°	0·26	
14	24	1·8°	1·4	2·1°	0·38	
15	24	1·8°	1·34	2·1°	0·9	
16	24	1·8°	1·5	2·1°	0·9	
17	24	1·8°	1·46	2·1°	0·72	

XII.—Silication of Huddersfield Water on the Large Scale.

It was now deemed advisable that experiments in the direction indicated, but of a more definite and practical character, should be made in properly constructed filter tanks. Accordingly experimental filters were erected, both at Deerhill and Blackmoorfoot reservoirs, as follows:—

The tanks were constructed of 1½-inch slate. They were 4 feet × 4 feet × 7 feet deep. A meter was placed at the top, in order to regulate the flow, and

the water was drawn through a tap at the bottom. The filter-tank was charged as follows, the layers being in the order of the lines of type.

2 ft.	...	...	...	...	...	...	Sand
1 ft. 3 in. ...	...	...	...	...	...	Broken flints
1 ft. 3 in. ...	...	...	...	...	...	Limestone

The arrangement was set so as to deliver 50 gallons per twenty-four hours for each square foot of surface. We further determined to attach to the delivery or exit stop-cock a lead pipe, 1·5 inch diameter, and 50 feet in length, in order that the action of the water, after filtration, might be taken note of.

The results, from November 5th, 1883, to February 15th, 1884, are given in the following tables.

In the case of each water, the reaction, the total solids, the initial hardness, and the quantity of silica are recorded.

We have in these tables expressed in arbitrary numbers the "lead-dissolving power" of the water, and not the quantity of lead dissolved. By lead-dissolving power is indicated the relative amount of lead which the water will dissolve under similar conditions. The figures recorded express the number of measures of a dilute standard solution of lead acetate required to give, with sulphuretted hydrogen gas, the same tint as that given by the gas to an equal volume of water subjected to the action of the metallic lead.

DEERHILL WATER.

	UNFILTERED WATER.					FILTERED WATER.				
	Re-action.	Total Solids	Initial Hard-ness.	Silica.	Lead dissolving power.	Re-action.	Total Solids.	Initial Hard-ness.	Silica.	Lead dissolving power.
1883.										
Nov. 5	Acid	4·0	1·6	0·12	30	Neutral	6·0	2·0	0·7	0
7	do.	5·0	1·6	0·10	20	do.	5·8	2·4	0·40	0
9	do.	3·6	1·6	0·00	15	do.	5·0	2·0	0·40	0
12	do.	3·0	1·6	0·10	10	do.	4·50	2·0	0·38	0
{ 14	do.	5·0	2·4	0·00	30 {	Slightly acid. }	6·0	2·85	0·38	0
16	do.	5·4	2·4	0·00	30	do.	6·70	3·75	0·40	0
19	do.	4·0	2·0	0·14	30	Neutral.	6·56	2·4	0·36	0
21	do.	4·48	2·0	0·14	50	do.	5·80	2·0	0·28	0
23	do.	3·84	1·6	0·22	40	do.	5·20	2·4	0·46	0
26	do.	4·65	1·6	0·10	40	do.	5·×0	2·4	0·40	0
28	do.	4·00	2·4	0·14	35	do.	5·00	2·4	0·34	0
30	Neutral.	4·83	2·4	0·08	28	do.	4·90	2·4	0·31	0
Dec. 4	Acid.	3·40	2·2	0·20	50	do.	5·07	2·6	0·48	0
8	do.	3·42	2·18	0·10	50	do.	4·50	3·1	0·14	4
10	do.	4·86	2·36	0·16	20	do.	6·32	2·82	0·22	4
{ 18	do.	5·10	1·82	0·14	35 {	Slightly acid. }	6·70	1·72	0·21	3
19	do.	4·87	2·0	0·18	35	do.	6·60	2·00	0·26	1
1884.										
Feb. 7	do.	4·06	2·18	0·16	30	do.	5·83	2·18	0·29	2
8	do.	4·36	2·73	0·16	25	do.	5·18	2·73	0·24	2
11	do.	4·84	3·19	0·12	20	do.	5·18	3·19	0·18	4
13	do.	3·40	2·0	0·08	25	do.	5·00	2·0	0·18	4
15	do.	3·84	2·27	0·08	25	do.	5·12	2·32	0·20	2

BLACKMOORFOOT WATER.

1883.	UNFILTERED WATER.					FILTERED WATER.				
	Re-action.	Total Solids.	Initial Hardness.	Silica.	Lead dissolving power.	Re-action.	Total Solids.	Initial Hardness.	Silica.	Lead dissolving power.
Nov. 5		5·10	2·4	0·15	28	Very slightly acid.	5·4	2·4	0·35	0
7	Very slightly acid.	5·75	2·4	0·10	18	do.	6·50	2·4	0·31	0
9	do.	6·50	2·0	0·18	15	do.	6·50	2·4	0·22	4
12	do.	5·40	1·6	0·10	31	do.	4·81	2·0	0·20	2
14	do.	4·40	1·6	0·10	24	do.	4·70	2·0	0·26	3
16	do.	5·60	2·4	0·10	16	do.	6·30	2·4	0·26	2
19	do.	4·20	2·4	0·20	7	Neutral.	4·70	2·4	0·30	1
21	do.	5·20	2·0	0·10	20	do.	5·30	2·85	0·40	0
23	do.	3·40	2·4	0·03	27	do.	5·00	2·40	0·20	2
26	do.	5·64	2·4	0·09	34	do.	6·46	2·85	0·36	0
28	do.	5·40	2·4	0·16	21	do.	6·34	2·40	0·19	6
30	do.	5·14	2·4	0·09	32	do.	6·14	2·40	0·18	8
Dec. 4	Neutral.	5·82	3·19	0·16	20	do.	6·14	4·10	0·36	1
8	Very slightly acid.	5·28	3·4	0·20	15	Very slightly acid.	5·30	3·5	0·36	2
10	do.	4·98	3·33	0·14	20	do.	6·04	3·33	0·28	2
18	do.	5·84	3·19	0·16	16	do.	6·06	3·19	0·26	2
20	do.	5·36	3·33	0·16	14	do.	5·86	3·33	0·32	1
1884. Feb. 7	do.	4·83	2·27	0·08	14	Neutral.	5·18	2·63	0·18	12
8	do.	5·22	3·30	0·10	20	do.	5·60	3·50	0·18	15
11	do.	4·22	2·27	0·06	30	Very slightly acid.	4·86	2·63	0·16	11
13	Neutral.	5·10	3·19	0·10	15	Neutral.	5·68	3·19	0·18	10
15	Very slightly acid.	5·30	3·70	0·12	10	do.	5·86	4·0	0·24	1

DEERHILL.—As regards Deerhill water it is noticeable that, whilst the unfiltered water was acid upon all but one occasion, the filtered water was neutral in more than 50 per cent. of the specimens.

The total solids were increased by filtration from an average of 4·27 grains per gallon to an average of 5·08 grains.

The initial hardness was increased by filtration from an average of 2·13 degrees to an average of 2·25 degrees.

The lead-dissolving power was decreased from 30 to 1, the silica correlatively increasing from an average of 0·115 grain per gallon to an average of 0·32 grain.

In no instance was any lead found in the water that had merely passed after filtration through the lead exit pipe attached to the filter-tank.

BLACKMOORFOOT.—In respect to Blackmoorfoot water the results are less striking. As regards reaction, the unfiltered water was only twice found to be neutral, whilst 50 per cent. of the filtered samples were so recorded.

The total solids were increased by filtration from an average of 5·16 grains per gallon to an average of 5·71 grains.

The initial hardness was increased by filtration from an average of 2·61 degrees to an average of 2·87 degrees.

I

The lead-dissolving power decreased from 20 to 3·9, whilst the silica correlatively increased from an average of 0·12 grains per gallon to an average of 0·26 grains.

Again, in no instance was any lead found to have been taken up by the filtered water in its mere passage through the lead exit pipe attached to the filter-tank.

We would note, in connection with these experiments, that the filtered waters were generally neutral. It is only right we should record this circumstance, because it was suggested that the solvent action on lead of the Deerhill water depended for the most part upon its acidity, a view we have ourselves never adopted. As a fact, we have observed on more than one occasion the Deerhill water to be perfectly neutral, its lead-dissolving power at these times being as marked as we had found it when the water was in its most acid condition. We are further of opinion that the alleged degree of acidity of Deerhill water, as stated by some observers, is largely in excess of the fact.

The total solids and the degree of hardness of the filtered water are, no doubt, slightly increased; but it would be difficult to believe that an addition generally of 0·8 grain of solids in solution, with an added hardness of 0·13 degree, could bring the lead-dissolving power of the water, as in the case of the Deerhill water from 30 to practically 0; or that an addition generally of a little more than 0·5 grain of total solids per gallon, with an added hardness of 0·26 degree, could decrease the lead-dissolving power, as in the case of the Blackmoorfoot water, from 20 to 3·9.

Further, whereas the experiments with Deerhill water were more successful than those with Blackmoorfoot, it is noteworthy that in the former (Deerhill) the silica of the filtered water afforded an average of 0·32 grain per gallon, whilst in the latter (Blackmoorfoot) the silica amounted to an average of only 0·26 grain per gallon.

There are many other important points to be noted in the tables. Thus, in the experiments with Deerhill water, it will be seen that the lead-dissolving power of the first thirteen samples is recorded as 0, whilst of the nine last samples the average lead-dissolving power is 2·9. We are not prepared to discuss the reasons for this result. It may be that the water did not come into perfect contact with the flints, owing to its having made short cuts for itself in the filter tank; or it may be that when the sharp edges of the flints had been taken off, the rounded surfaces were less easily acted upon by the water, etc. But be the explanation what it may, it is remarkable that, whereas the average silica of the first thirteen experiments (when the preventive action was complete), was 0·407 grains per gallon, the average silica per gallon of the last nine experiments (when the preventive action was incomplete) was only 0·212 grain. Further, if the samples are arranged in the order of their lead-dissolving powers, this will be found to be the inverse order of the quantities of silica present. Thus:—

DEERHILL WATER.

Lead dissolving power.									Silica.
0	...	...	...	...	...	...	...	...	0·407 gr.
1	...	...	...	...	...	...	...	...	0·26 ,,
2	...	...	...	...	...	...	...	...	0·24 ,,
3	...	...	...	...	...	...	...	...	0·21 ,,
4	...	...	...	...	...	...	...	...	0·18 ,,

Again, it will be noted that as regards the Deerhill water, in no instance (save one) does the silica of the samples without action on lead, fall below 0·3 grain per gallon; whilst in the nine cases where the waters do act on lead, in no instance does the silica reach 0·3 grain per gallon.

Passing on to Blackmoorfoot water, with which the results, as we admit, are less satisfactory, the same general order manifests itself in comparing the lead-dissolving power with the amount of silica present, although indeed the regularity is somewhat broken after the lead-dissolving power reaches 8. Thus :—

BLACKMOORFOOT WATER.

Lead dissolving power.									Silica.
0	...	...	...	...	...	...	...	...	0·35 gr.
1	...	...	...	...	...	...	...	...	0·30 ,,
2	...	...	...	...	...	...	...	...	0·26 ,,
3	...	...	...	...	...	...	...	...	0·26 ,,
4	...	...	...	...	...	...	...	...	0·22 ,,
6	...	...	...	...	...	...	...	...	0·19 ,,
8	...	...	...	...	...	...	...	...	0·18 ,,
10	...	...	...	...	...	...	...	...	0·18 ,,
11	...	...	...	...	...	...	...	...	0·16 ,,
12	...	...	...	...	...	...	...	...	0·18 ,,
15	...	...	...	...	...	...	...	...	0·18 ,,

Certainly, neither the variations in the total solids nor in the hardness, would explain with even an approach to accuracy, that upon which the increase of the dissolved silica appears to us capable of throwing an unmistakable light.

We desire to note this further, that in no case, although the lead-dissolving power of the water was not completely overcome, could any lead be found in the water that flowed through the lead exit pipe; a circumstance we explain by supposing that the coating of silicate of lead already formed was sufficient to protect the pipe for awhile, although the mere silica in the water might at some times have been of itself insufficient.

XIII.—PROPORTION OF LEAD PERMISSIBLE IN DRINKING WATER.

The question arises as to what is the maximum quantity of lead permissible in a water used as a supply for potable purposes?

Noad refers to a case where water containing $\frac{1}{20}$th gr. of lead per gallon was used habitually by a family without obviously injurious results; and Dr. John Smith, of Aberdeen, states that "less than $\frac{1}{20}$th of a grain of lead per gallon produces no deleterious effect."

In the Claremont case the habitual use of water containing 1·3 gr. of lead per gallon produced poisoning in 4 persons after 5 months', and in 13 persons after 7 months' use. (Case 10.)

Herapath (*Times*, Sept. 14, 1850) mentions a case where water containing $\frac{1}{9}$th of a grain of lead per gallon proved harmful.

The Boston Committee of Physicians state that rare cases occur in which disease has been produced by less than the 0·01 gr. of lead per gallon of water, and where sulphuretted hydrogen showed no trace of lead in the water. (See Case 3, Tunbridge Wells case; also page 25.)

Herapath (*Pharmaceutical Journal*, 1858, 59 and 618) states that he has met with cases of injury arising from lead in water where the lead could not be detected by passing sulphuretted hydrogen through it.

Our own experiments lead us to believe that if the action of sulphuretted hydrogen on a few ounces of the water be not apparent without concentration of the water by evaporation, the quantity of lead present may be taken as practically *nil*, and this independently of its precise form of combination.

So far as we know, there is an absence of any direct evidence to show that water containing not more than $\frac{1}{20}$th of a grain of lead per gallon has been productive of harmful effects.

It is indisputable that considerable quantities of lead may be taken into the system by very many people without any injurious effects whatsoever manifesting themselves. In connection with this it is noticeable that in at least three towns, not including Huddersfield, of which the water supply came under our examination, although the supplies delivered through the lead services would seem to contain habitually an appreciable proportion of dissolved lead, ranging from 0·05 to 0·50 grain per gallon, yet the cases of reported or alleged lead-poisoning were of very rare occurrence in these towns, and for the most part not of a well-demonstrated character. Indeed it is a matter for surprise, not that a few people should be affected, amongst those exposed to the action of a lead water, but that so few people are found to be affected. Without doubt cases may and do occur which are unrecognised or are not attributed to their true source, because of their slow and insidious character. We would point out that if a lead water, containing 0·5 gr. of lead per gallon, be used for making tea, the quantity of lead in the tea infusion may be reduced to less than $\frac{1}{100}$th part of that in the original water, the chief part of the lead being found in the tea-leaves; and that much the same abstraction, though to a somewhat less extent, occurs in the case of coffee.

XIV.—Concluding Practical Suggestions.

With these results before us, your Committee will naturally ask what suggestions of a practical nature we have to offer.

I. We deem it impracticable, even were it advisable, which we doubt, to replace the lead pipes by iron pipes, or by pipes of tinned lead. And even supposing we were able to suggest some protective coating for the lead pipes, it would be a huge undertaking and entail a heavy expense, to take up hundreds of miles of lead pipe already laid and to replace them by pipes of improved construction.

As regards tinned lead pipe, the tinning is found to be not only detrimental to the strength of the lead, but is likely, unless the coating be perfect, to assist the dissolution of the lead.

Iron pipes, although strong, and safe so far as health is concerned, are more likely to break, more difficult to adjust and repair, very easy of oxidation, and liable to obstruction from accumulation of the oxide. We are not able to say how far some of these evils might be met by lining the service pipes with Angus Smith's or other innoxious material, such as a silicious glazing.

Tin also is acted upon by water, although no doubt its toxic action is far below that of lead. It is fairly flexible, but four times as expensive as lead. Being, however, a more tenacious metal than lead, a thinner tin pipe would suffice. But there is reason to believe that waters do not afford a protective coating to tin in the same manner that they habitually do to lead.

The advantages of lead service pipes are their cheapness, durability, flexibility, and the ease with which they can be wrought and repaired.

II. We consider that our results, as set forth in the pages of this Report, warrant us in recommending with confidence the systematic and continuous filtration of the water, recourse being had to such modifications of the ordinary filter-bed as will ensure the efficient silication of the water. Efficient silication would, in our belief, minimize to the utmost, and practically altogether prevent, the action of the water on the lead services; thereby effecting a real hygienic improvement, and allaying the justifiable apprehensions of consumers, as to the possibility even of injury resulting to them from the lead-dissolving character of the water-supply. Such filtration would, moreover, in a special manner improve the brightness and colour of the water, and would lessen the quantity of organic matter held in solution.

We have the honour to remain,

Gentlemen,

Your obedient Servants,

WILLIAM CROOKES,
WILLIAM ODLING,
C. MEYMOTT TIDY.

ILLUSTRATIVE CASES.

POISONING BY LEAD IN WATER.

1. *American Journal of Med. Sc.*, LXVII., p. 279 (Earle).—A family (6) affected with acute lead poisoning from the use of water boiled in a kettle that had been used for melting lead. The symptoms occurred after ten days' use of the kettle for cooking purposes. All the family recovered.

2. *Transactions of London Coll. of Phys.*, II., 400, Christison, p. 258 (Dr. Wall, of Worcester).—A family (parents and 21 children) constantly suffered from severe colic. Parents and 8 children died. The illness was traced to the use of water from a pump, the lead cylinder of which was found riddled with holes and as thin as a sieve. The water contained much lead.

[The plumber said that the pump had been repaired four years previously, just after the death of the former occupant. Christison thinks there must have been some galvanic action in this case.] (page 536.)

3. *Journal of Science*, XIV., p. 352 : *Scudamore's Analysis of the Mineral Water of Tunbridge* : Appendix Christison, p. 529 : (Yeats of Tunbridge).—Tunbridge, in 1814, was supplied by water brought a distance of a quarter of mile through lead pipes. In 1815 many cases of lead colic were reported, one lady (a great water drinker) losing the use of her limbs for some months. Iron pipes were then substituted for the lead mains, after which no cases of lead colic occurred.

Analysis of water by Dr. Thomson, of Glasgow, gave :—

Total solids, per gallon	1·84 grs.
Chloride of sodium	1·38 grs.

Note.—In this case certain chemists found no lead in the water. This was probably due, says Christison, to the water having been exposed to the air for some time before analysis, the deposition of lead carbonate having taken place.

4. Christison, p. 530.—Three cases of lead poisoning reported :—

(A.) Case in Dumfriesshire. Spring water brought to a house through three-quarters of a mile of lead pipe and stored in a leaden cistern. (Christison approved of this, seeing that he found a tumbler full of water did not act on fresh cut lead for fourteen days.)

On examining the water as it came to table, however, it presented a general white haze, the glass decanters in general use acquiring a white and pearly crustation. Examining the cistern, it presented the appearance of being coated with white paint. The water from the pipe when first drawn was clear, but it became turbid from a white deposit after exposure to air or when heated.

It gave on analysis, total solids, 3·18 grs. per gallon.

Christison notes that his experiment with the water in the tumbler was not of the same character as the transit of the water through 4,000 feet of three-quarter inch pipe, where each portion of water may be taken as passing successively over 784 square feet of lead.

(B.) *Case in Banffshire.*—A gentleman brought water to his house from a spring three-quarters of a mile distant through a lead pipe.

The water gave, on analysis, per gallon (Christison) :—

Total solids	4·2 grs. (chiefly NaCl).

Two and a half years after he had first used the water, he was attacked with obstinate constipation and severe colic, for which he continued under treatment for three months. He did not improve until he left home, when he soon recovered. The symptoms returned, however, on his return. Two other members of the family were similarly (although less actively) affected, and recovered on leaving home. (The water bottle in the dressing room was noted to have a white film upon the inside.)

(C.) (P. 531.) See *Edin. Royal Soc. Trans.*, XV., 265.—Country residence of Lord Aberdeen, at Peterhead. A spring of water was brought to the house through a lead pipe. After eight months' use, the housekeeper was taken ill with vomiting, constipation, acute pain in pit of stomach, retraction of navel, and great feebleness. A girl who had lived only a few weeks in the house also suffered. (These were the only two people who had lived in the house for periods longer than a few days during the year of this supply.)

The water gave per gallon, total solids ... ... 15·7 grs.
(Mostly chlorides.—No carbonates.—Sulphates, 2·18 grs.)

The water was clear as it came out of the lead pipe, but contained lead in solution. On exposure to air a white film formed on the surface.

5. *Duncan's Medical Commentaries*, XIX., p. 1313 (Christison, p. 533).—The officers of a certain East Indian packet kept their drinking water in a leaden cistern, whilst the crew kept their drinking water in bottles. After three weeks, the officers suffered from lead colic, but the crew had perfectly good health. The water drank by the officers turned dark when sulphuretted hydrogen was added to it.

6. *Lambe on Spring Waters*, p. 14.—Warwick Water is stated by Lambe to act on lead with such great rapidity, that he once saw holes and furrows in a cistern in which it was kept, the cistern being the second that had been up within ten years.

7. *Lambe on Spring Waters*, p. 116.—Lord Ashburnham's house in Sussex, supplied by spring water conveyed through a leaden pipe. The water was contaminated with lead on delivery. The servants were often affected with colic, which in some cases even proved fatal.

(The solvent power of this water was ascribed to its containing an unusual quantity of carbonic acid. Christison doubts this.)

8. Christison, p. 533 (Van Swieten, 1753).—A whole family attacked with lead colic from using water for cooking that had been collected in a large leaden cistern and kept there for some time.

9. Christison, p. 534 (case read before the Academy of Sciences at Paris in 1788, and recorded by the Comte de Milly).—River Seine Water used for the house supply was kept in two leaden cisterns fitted with leaden covers. After a year the Count was attacked with lead colic. Examining the cisterns, he found that the sides where the lead had been occasionally exposed to the air, as well as the leaden cover of the cistern, was covered with a white liquid, which constantly dripped from the lid into the cistern. The water, in consequence, was strongly impregnated with lead.

10. *Dublin Quarterly Journal*, May, 1849, Vol. VII., p. 405 ; *Medical Gazette*, XLIV., p. 260 ; *Pharmaceutical Journal*, Vol. X., p. 61 (Dr. H. Gueneau de Mussy).—A series of cases of lead poisoning occurring amongst the members of the ex-Royal family of France, traced to drinking a water of great natural purity that by contact with lead had dissolved from ¼th to 1 grain of lead per gallon.

Thirteen out of 38 persons were affected ; the nails of the toes and fingers became blue.

The children in the family did not suffer.

No symptoms appeared until the water had been drunk from 5 to 7 months.

More than half of those that used the water escaped ill effects.

The following is the full account :—

I was summoned to Claremont in the beginning of October, 1848 ; and on my arrival was immediately shown into the room of one of the members of the family, who had been residing there since the preceding March. I found him lying down, with an anxious countenance, the conjunctiva of a yellowish colour, and the flesh flabby, evidently proving a loss of substance. He told me he had been suffering for several days from violent colic, which had been relieved after a constipation of two days, by abundant alvine evacuations, produced by a purgative draught.

This was the third attack of the same nature during the space of five weeks. Some time before, towards the end of July, he had been suffering from colic, with nausea, frequent eructations, and irregularity of the bowels.

<center>o   o   o   o   o</center>

I learned that a brother of my patient had experienced the same symptoms ; but no one was astonished at it, as it was supposed he was suffering under a liver complaint contracted on the western cost of Africa.

<center>o   o   o   o   o</center>

A third patient of forty-eight years of age, who was also subject to constipation, had violent colic a few days before, attended with nausea, and even vomiting.

<center>o   o   o   o   o</center>

A few days elapsed, and no bad symptoms disturbed our security. My patients had resumed their usual occupations, had good appetites and pretty fair digestion, but were still very weak, and pale sallow complexions had replaced the icteric colour. My delusions did not last long. About ten days after, a new access of symptoms began, with a painful sensation of constriction about the epigastric region, anxiety, nausea, and eructations.

After describing the symptoms and the treatment resorted to before the real cause of the disorder was suspected, the doctor mentions the circumstances that led to the discovery

which induced him to administer sulphur in combination with iron internally, and to order sulphurous and soapy baths. He proceeds—

The chemical action showed itself almost immediately by the black discolouration of the nails of the feet and hands, and by the appearance of similar spots on different parts of the skin. One of the patients came out from the second bath with the abdomen entirely black. The soapy frictions and baths usually washed away the spots from the skin, but not those of the nails. The appearance of this reaction—which is very common with men working in lead manufactures when using sulphurous baths—is explained by the combination of the sulphur with the saturnine molecules adhering to the skin. In these cases it was evident that the lead was brought to the surface of the body by means either of the sudaminal or follicular exhalation, and perhaps by both. The metal is eliminated and transformed into sulphuret of lead by the sulphurous baths, and then taken off by the soapy frictions and baths. These were not useless, for without them the lead deposited on the surface might have been carried again, by absorption, into the economy.

But the skin was not the only means of giving exit to the poison, I discovered it in the urine, by a solution of hydrosulphate of ammonia.

Some physicians and chemists look on sulphur as the only efficacious remedy ; others, on the contrary, assert that it is without any effect. What I can tell you is, that the success was beyond my hopes. After two or three weeks, I had the satisfaction of seeing my patients progressing rapidly and surely towards recovery. This happy result induced me to try the same means with another person, older and of a weaker constitution, and consequently, for whom I was most uneasy, and the results were as satisfactory.

     ✿   ✿   ✿   ✿   ✿

One of my patients was accustomed to drink Vichy water at table. This was a very unfortunate predisposing circumstance ; it is probable that the salt of Vichy water, *i.e.*, bicarbonate of soda, united to the lead of Claremont water, had much to do with the violence of the attack under which he suffered.

At the time of my arrival at Claremont, there were 38 inhabitants. Thirteen of these have been attacked—11 men and 2 women. Four of them had some symptoms two months previously to my arrival, the other cases occurred under my own eyes. Some, even after the pipes had been cut off, were affected, and one when on the Continent, a week after leaving England. Six children in the household, aged from three to seven years, have been exempt from it. Only half of the patients have had the gums marked with the slate-coloured line, and spots of the same colour on the mucous membrane of the mouth ; and these spots and the blueish line of the gums, were observed on several others who did not experience or exhibit anything else ; and those signs of the poison having been taken into the economy have not yet disappeared. The morbid cause has acted in these cases, as it often does, with caprice, and according to individual dispositions which defy every reasoning. The malady has shown no respect for condition, and attacked indiscriminately servants, aides-de-camp, and princes.

     ✿   ✿   ✿   ✿   ✿

The spring that furnishes the palace of Claremont with water, issues from a sand-bed at about two miles distance. It was chosen for its uncommon purity from among a great many others in its vicinity, and the water was, thirty years ago, conducted to the palace through leaden pipes. In the present day, some other metal would, perhaps, have been selected, for experience has taught us that pure water, and especially distilled water, acts rapidly on lead when it comes in contact with it.

Thus Tronchin proved that the inhabitants of Amsterdam were indebted to the rain water, kept in leaden cisterns, for the colic they were so much subject to in his time. The purity of the Claremont water becomes a most dangerous property, and not only to it but to other springs. Whilst I was combating its pernicious effects, I heard that there had been several similar cases in different parts of England ; they are not uncommon in the county of Surrey, and especially in the neighbourhood of Claremont. Besides the cases published by Dr. Thomson, I know of several others at Weybridge, Windsor, and in different other places.

The water of the palace of Claremont had been for many years employed by its inhabitants without any bad result ; how was it, then, that this water, till now harmless, had become suddenly a violent poison ? This is what has puzzled me and everybody else ; and although I looked for its cause with the greatest attention, I could discover only a single alteration, apparently of little importance, lately made in the transmission of the water.

Until about eleven months ago, leaden pipes used to take up the water from a large natural cistern near its source. When the present occupants of the palace came to live in it they wished to preserve this natural cistern from the vegetable and animal detritus that usually fell into it. For this purpose an iron cylinder of 6 feet in diameter and 20 feet high was constructed,

and was sunk in the ground 15 feet deep. The water swelled up within, and a leaden pipe was attached to it with a funnel-like mouth projecting by a few inches in the inside of the cylinder, which was closed at top by an iron cover with several holes in it to allow the air to make the requisite pressure on the surface of the water. You may discover what has been the influence of this change; for myself I think it has been the origin of all the evil. The datum is certain, but I have only hypothesis to offer as to the chemical reaction of the water. Mr. R. Phillips, so well known for the accuracy of his researches, has, however, analysed the water of the spring, and has only found in a gallon of it 5·7 grains of solid and saline matter, consisting of

Common salt	2·7 grs.
Sulphate of lime. silica, oxide of iron, and vegetable matter	3·0 „
	5·7 „

That is to say, a proportion of salts, and especially of sulphates, too small to prevent the formation of hydro-carbonate of lead, for experiments have proved that $\frac{1}{400}$ of sulphate is necessary to prevent the development of the deleterious salts.

As for the part acted in this case by the iron cylinder, I must look for it, first, in the galvanic action resulting from the contact of the two metals with the water. I have, however, some hesitation in admitting this supposition, for it seems to me that the water contained in the cylinder should be charged with more lead than that which ran through the pipes and remained for some time in the leaden cistern of the palace; and yet the water of the iron cylinder did not contain any lead, that of the pipes contained some, and that of the cistern contained much more of it. Secondly, in the action of the iron on the water, and on the salts which it contained; and, thirdly in the very purification of the water, caused by the enclosure of it in the iron cylinder, and the filtration which it underwent to get into it. We may understand this better at some future day.

For the present I hope I have said enough to impress upon my readers the danger of using water that has been in contact with lead, a danger *increased in proportion to its purity*, and to point out the bad effects that are likely to arise from transmitting water alternately through lead and iron conduits.

  ✻   ✻   ✻   ✻   ✻

I should inform you that Professor Hofmann has ascertained the quantity of metallic lead contained in the water examined by him. He has found that it amounted to a grain per gallon, an enormous quantity, when we consider that the poisoned water was used in all culinary and table purposes, and previously to the discovery of its deleterious character, even in the preparations of tisans and lavements.

11. *Lancet*, 1851, I., p. 202 (Robertson).—A school of 20 girls suffered from general ill-health, anæmia, loss of appetite, offensive breath, constipation in some cases, diarrhœa in others (fæces clay-coloured). Certain of the girls had the symptoms more marked than others. In some cases even delirium, faintings and fits are recorded as having occurred.

The illness was traced to the use of a well water (from the chalk), which was stored in a leaden cistern and used for drinking. The water was clear and sparkling. On examining the cistern, the surface of the water was found to be covered with an iridescent film. The cistern was coated with a white deposit of mixed lime and lead carbonates. Lead was found in the water. Upon the use of the water being discontinued, the children recovered.

12. *Pharm. Journal*, 1858-9, p. 618 (Herapath).—A case recorded where a whole village suffered from poisoning symptoms (loss of appetite, listlessness, pains and loss of strength in legs, costiveness, &c.), in the neighbourhood of lead mining operations. The water to which the symptoms were attributed contained 0·035 grs. per gallon. One man had colic after drinking a large quantity of this water.

13. *Edin. Philosophical Journal*, X. (1859), p. 13 (London : Lindsay).—Male adult (one of a family of 19) affected by lead from drinking water. None of the other members affected.

House supplied by two springs, one " excessively hard," the other " excessively soft." Both waters flowed through iron pipes into leaden cisterns.

Lead was found in the hard water after storage in the cistern. The water contained—

Total solids	14·87 grs.
Of which inorganic	11·37 grs.

14. *British Med. Journ.*, 1878, I., p. 301 (Fussell).—Male, æt. 53. Severe lead poisoning from drinking water containing lead, the lead being derived from a leaden pipe in a well. (Lead was found in the urine of the patient.) No other member of family (3 in number, viz., wife and 2 daughters, æt. 12 and 14) suffered, nor in their cases was any blue line visible.

The man was supposed to be suffering from cancer of the bowels, and was thought at one time to be dying.

K

[Beyond the slight blue line the symptoms were far from characteristic. The case seems doubtful as being due to lead. – C.M.T.]

15. *Milnes* v. *Borough of Huddersfield.*—Leeds Assizes, Aug., 1882.—The plaintiff, a solicitor, age 35, suffered from lead poisoning, due, it was alleged, to drinking the town water (Black-moorfoot) which, on passing through a lead service pipe, dissolved lead in such quantity as to render it injurious. The other members of his family were not affected. The symptoms from which the plaintiff suffered commenced in 1875 (colic, constipation, sleeplessness), but yielded again and again. With the last attack paralysis set in and became serious. The water, after passing through the service pipe, contained about ·2 to ·3 grs. of lead per gallon, and there was no dispute that the plaintiff suffered from lead poisoning. The jury found for the plaintiff, with £2,000 damages.

The point of law reserved, was that the Corporation having supplied the water authorised by Act of Parliament, the water in the mains being pure and wholesome, were not liable. The water became unwholesome by passing through the lead service pipes, which did not belong to the Water Company (*i.e.*, the Corporation), but to the landlord who paid for putting them down. The case was complicated by the Corporation having laid the lead service pipes, but only in the position of tradesmen doing what they were paid for. Mr. Justice Mathew decided the point in favour of the Corporation, and this was confirmed on appeal.

16. *British Medical Journal*, 1882, II., p. 886 (Dr. Dobie).

Full account of Keighley case (from *Pharmaceutical Journal*, September 9th and October 7th, 1882) :—

Alleged Death from Lead Poisoning.

An inquest was held on August 29th, 1882, at the Keighley Cottage Hospital, before Mr. T. P. Brown, touching the death of William Wilson Riley, 42, who, it was alleged, had died from lead poisoning. Mr. George Burr, Clerk to the Local Board, watched the case on behalf of that body. There were several members of the Board also present.

Sarah Riley, the widow, deposed that her husband died on Saturday, the 26th inst., after being confined to his bed for a short time. He had had pretty good health, except being troubled with sick headache. He was in the Kildwich railway accident, about seven years previously, which made him rather nervous, and he had never seemed to recover from it. Her husband suffered from lead poisoning about two years ago, and she herself had had an attack of it.

Dr. William Dobie deposed to having twice seen deceased during his late illness, and found him to be suffering from symptoms of lead poisoning. *Post-mortem*—No marks of external injury, and the body showed the usual marks apparent after death. There was no dropsy. The body was wasted, but not extremely so. The left wrist presented an appearance of what is known as a "dropped" wrist. The brain was a little paler than usual, but otherwise healthy. The lungs were quite healthy, though there was an old standing of pleura covering them. The bag of the heart was quite natural ; the heart somewhat enlarged. The stomach was natural. The appearances of death were not inconsistent with death from lead poisoning. The "dropped" wrist and the constricted condition of the large bowel especially pointed in that direction, but he would not dogmatically like to say that that was the cause of death. The proof would not be complete until a chemical analysis was made of the viscera.

In reply to the Foreman, witness said he did not find sufficient disease to cause death except from lead poisoning. Deceased visited him about two years ago, and then he was suffering from lead poisoning. At that time he advised him to discontinue using the water.

Witness said he had reported 64 cases to the Local Board twelve months ago. The lead was dissolved from the pipes by the action of the water. It was his opinion that, but for lead poisoning, the deceased would have lived an average life.

By Mr. Burr : If the deceased's symptoms had not been known to him he should have inferred after he had made the *post-mortem* examination that lead poisoning had been the cause of death. He was not aware that deceased had been in the Kildwick railway accident.

The viscera of the deceased and a sample of the town's water from the mains and tap of the deceased's late residence had been submitted to Mr. Alfred H. Allen, of Sheffield, for analysis, and the following is an extract from his report supplied to the Coroner :—

"A doubtful trace of lead was found in the kidneys, but in the liver and spleen a notable quantity of lead and copper was found. There was ⅛ of a grain of lead in one-half of the liver. That amount was smaller than they might expect to find in the liver of a person who was poisoned by lead, but he had not unfrequently noticed very insignificant amounts of lead in the viscera of cows and other animals that had undoubtedly met their death by lead poisoning. He attached no importance to the finding of copper, as he had met with it in several other instances. He had examined a sample of water from the tap in the

deceased's dwelling-house, and found that it contained $\frac{2}{5}$ of a grain of metallic lead per gallon. The proportion was amply sufficient to produce poisonous effects, but some persons appeared to be more sensitive to the influence of lead than others. Speaking generally, anything over $\frac{1}{10}$ of a grain of metallic lead per gallon of water was a dangerous contamination. He had known $\frac{1}{5}$ of a grain of lead produce severe symptoms of lead poisoning. On examining a sample of the water taken direct from the mains he did not find any trace of lead, but it contained a distinct trace of mineral acid. The water, by remaining in contact 18 hours with a strip of clean lead, became contaminated with lead to the extent of $0\cdot56$, or over $\frac{1}{2}$ grain per gallon. A repetition of the experiment showed that $0\cdot45$ of a grain of lead was taken up in 14 hours. Those proportions of lead would render the water highly injurious to a person who drank it regularly. When the water in question was rendered faintly alkaline with lime water, and left in contact with lead over one night, it took up the smaller quantity of $0\cdot14$ grain of lead per gallon. From the experiments he considered it was the free acid in the water that gave it so great a tendency to act on the lead. He found that Sheffield water took up a small trace of lead during one night, but Rotherham water took up no trace of lead after two nights' contact with metal."

Mr. Allen was called, and said he arrived at the conclusion, when he found no lead in the heart, that it had been eliminated by medical treatment. On good authority he believed that a person under medical treatment could be freed from lead in a fortnight, but the organs would show deterioration.

By Mr. Tindal Atkinson : One-fifth of a grain was not sufficient to cause death, but it would cause paralysis.

Dr. William Dobie was then called. In examination by Mr. Atkinson, he said that disease of the kidneys generally accompanied lead poisoning. They might find symptoms of paralysis without lead poisoning, but in aggravated cases of lead poisoning paralysis was generally found.

By the Foreman : The deceased might have died from granular disease, caused by lead poisoning. (1.) Lead poisoning was a very common cause of granular disease. (2.) During life there were unmistakable signs of lead poisoning. (3.) Lead was found in the tissues after death.

By Mr. Atkinson : Witness had treated deceased for lead poisoning about two years ago, Lead might be eliminated from the system after ten days of medical treatment. He accounted for the absence of lead in other organs of the deceased from the fact that it was being rapidly eliminated from the system by medical treatment.

Dr. William Jack, who attended deceased up to the time of death, gave his opinion that the cause of death was lead poisoning.

Charles Meymott Tidy, M.B., Master of Surgery and official analyst to the Home Office, was examined. He said he had had great experience in cases of poisoning. In this case the lead poisoning did not appear to be the actual cause of death, but to have preceded death. Deaths from lead poisoning were not very rare occurrences. When lead poisoning was very advanced, and caused death, paralysis of the muscles—especially the muscles of the wrist—or some brain lesion, was almost an invariable symptom. Granular disease of the kidneys resulted in some cases from lead poisoning. He had read Mr. Allen's report, and he was astonished to see the small amount of lead found in the system, for in one case, which had not resulted in death by lead, he had found 5 grains of lead in the spleen and 4 grains in the liver. Iodide of potassium was said to be a remedy for lead poisoning, but it was difficult to understand its *modus operandi*. The effect of iodide of potassium upon lead was to form a somewhat insoluble iodide of lead. It was difficult to say in this case what was the cause of death, because he was not present when the *post-mortem* examination was made. There was very little lead found, and that led him to suppose that death was as likely to be due to granular degeneration of the kidneys as to anything else. There was no evidence of disease of the nerve centre.

Dr. Jack, who attended the deceased, was recalled and made additional remarks. He said the deceased vomited, but the vomit had not the appearance of being caused by disease of the kidneys. The deceased was never above the natural heat. The temperature always rose from inflammation. The deceased's breath had a peculiar fetid odour, which he had never noticed before except in cases of severe lead poisoning. He also complained of pains in the arms and legs, which constantly shifted. Shortly before death convulsions set in, and the deceased was attacked by severe pains. All the medical men were of opinion at the *post-mortem* examination that the deceased had died from lead poisoning.

The Coroner, in summing up, said the jury need not attach any importance to the small quantity of lead found in the deceased.

Mr. Atkinson, addressing the jury, said, whatever the result of the inquiry might be, he

was instructed by the Local Board to say that the most searching investigations would be made with regard to the town's water.

The jury retired to consider their verdict, and after being absent for two hours, the foreman handed in the following verdict :— " We are of opinion that the deceased, Wilson Riley, died from granular disease of the kidneys, but how caused we are unable positively to say ; but death was accelerated by lead poisoning."—*Leeds Mercury*.
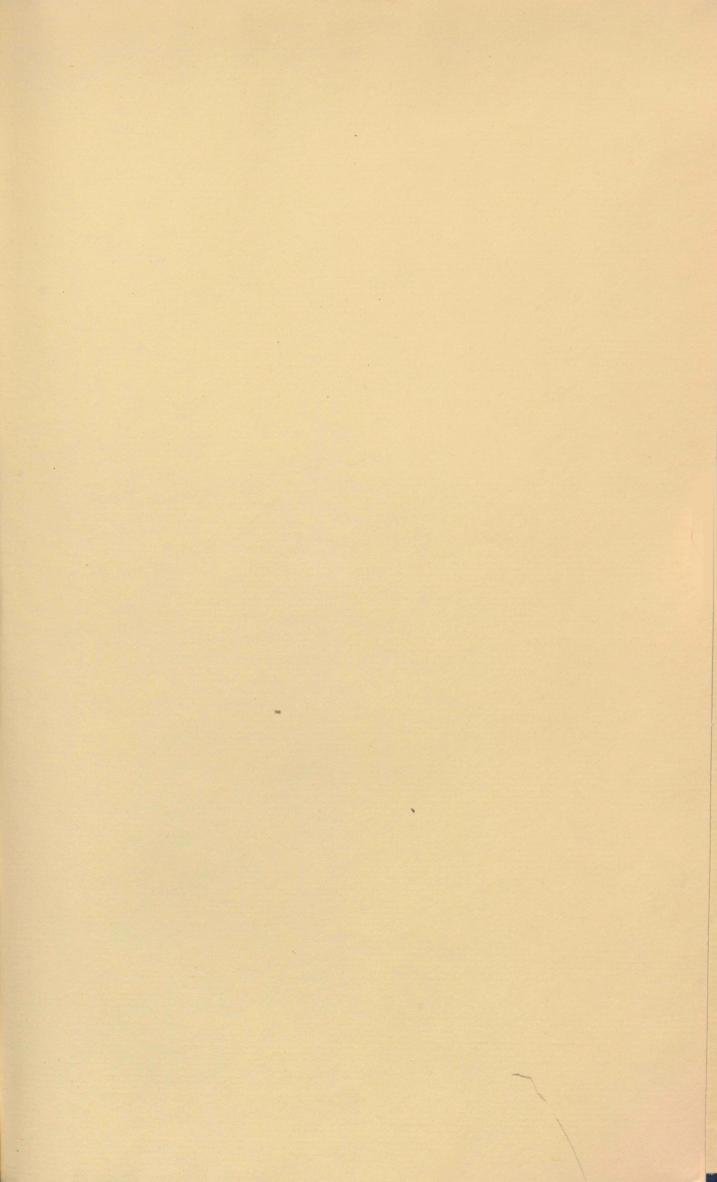
17. *Lancet, September* 29, 1883, pp. 560, 612.—An outbreak of lead poisoning occurred at Ebbw Vale and at Tredegar. Certain samples of the water supplied to these places were found to contain lead, and the outbreak was believed accordingly to be due to this cause.

18. *Lancet, June* 28, 1884.—(1.) Lead poisoning from drinking water conveyed by means of a lead pipe from a well in a garden to the house pump. (The predecessor of the patient, the owner of the house, had also suffered, but did not discover the cause.) (2.) Lead poisoning from water conveyed through lead. The case was supposed to be " cancer of the stomach." Recovery. (See Case 14, which is similar.)

19. *Lead Pipe Reports*, p. 137.—A series of cases of lead poisoning in 1836 are recorded by Dr. Stimson (Dedham, Mass.), due to water conveyed to the village through about half-a-mile of leaden pipes. Most of the cases recovered when the use of the water was abandoned. Some of the cases were fatal.

Several occurred in adults. One in a girl, æt. 14.

A case is recorded where a man had lead colic for two months, and paralysis for three months after he had discontinued the use of the water.

20. Cases of poisoning by drinking water contaminated by lead are recorded at Norwich, Connecticut (April, 1858). The water from certain small springs was impounded in cement cisterns (5), and supplied by lead pipes to certain of the inhabitants. A lead main (1½ in.) supplied the water. In one case Dr. Chilton, of New York, found the water to contain 4 grains of lead per gallon, and in a second Professor Doremus found 0·6 grain per gallon.

Some of those who had used the water had severe paralysis. One case proved fatal. The use of the water was discontinued, and the patients recovered.